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PREFACE

CONSIDERING the great and rapidly increasing importance of the margarine industry during many decades, it is strange that so little has been published about its science and technology. In some of the best-known books on the industry of fats and oils a chapter is devoted to margarine, the most comprehensive being those by G. HEFTER: *Technologie der Fette und Oele, vol. III*, Berlin 1910, and by H. SCHÖNFELD: *Chemie und Technologie der Fette und Fettprodukte*, vol. II, Vienna, 1937.

Of separate books on margarine technology there is in this country only the monograph by W. CLAYTON, *Margarine*; there are also some rather small German books twenty-five to thirty years old.

Since these books were written, far-reaching developments have taken place in the margarine industry, not only quantitatively, but also in its technology, chemistry, physics and nutritional aspects. While originally essentially of importance in Europe the industry is now well established in practically all countries, and matches in importance that of the butter industry, for the supplementation of which it was first introduced.

The Author has endeavoured in the first chapter to give a brief survey of the invention and further development of the margarine industry, its nutritional and statistical features.

The next chapter deals with the fatty raw materials, the milk and the ingredients, and a brief résumé is given of the chemical nature and characteristics of fats and oils as a basis for their evaluation for suitability for margarine. The preparation of fatty raw materials prior to their use for margarine is not included, and those interested are referred to the Author's recent book, *Refining of Oils and Fats* (Pergamon Press Ltd., London, 1953). The bacteriological processes, involved in the preparation of milk, are dealt with in some detail, but only as regards their practical application; the biochemical side is only described as far as considered necessary to explain the practical importance.

In the chapter on processing, the various steps for converting the raw materials into the final product are described, and their chemical, physical and engineering features are explained. Older and well established methods, which are still successfully used, as well as the newer and the very latest methods and plants are considered. Reference is also made to some interesting, but now largely obsolete methods, as it is the Authors experience that they continue to crop up in suggestions from new entrants to the industry.

As margarine is often described as a "perishable food", a chapter is devoted to storage and preservation and the hygienic features in this connection.

The Author considers it outside the scope of this book to deal with details of analytical methods, but reference is made to several important books on that subject. Suggestions are, however, made in many places as to suitable methods.

Finally, a survey is given of the statutory regulations governing the manufacture and composition of margarine in a number of countries, where it has become an important item in the dietary.

It has been the Author's privilege to be actively engaged in or closely associated as a consultant with the margarine industry in large, medium and small factories in many countries for close on half a century, during which time important changes have taken place in the industry. He would like to express his appreciation to colleagues in the industry in various countries for many helpful discussions. He also wishes to record his indebtedness to many firms for generously placing at his disposal information, drawings, illustrations and blocks for reproductions, namely:

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Drawings and information supplied in past years by such well-known makers of plant as *Bergedorfer Eisenwerke*, Germany, *H. Grasso Machinefabrieken*, Holland, and *Harburger Eisen und Bronze Werke*, Germany, have also been made use of in selecting illustrations representative of what is used in the different types of plant installations.

London, 1954.

THE AUTHOR.

I. INTRODUCTION AND HISTORY

INVENTION

MARGARINE is a fatty food resembling butter in appearance, character and composition and is used as a substitute for or alternative to butter. The statutory definitions vary in the different countries, but usually the description Margarine is applied to fatty foods similar to butter except that the fat is not, or only to an insignificant extent, derived from milk fat. (See page 295.)

Margarine is a solid emulsion of a fatty phase, consisting usually of a mixture of vegetable or animal fats and oils, and an aqueous phase, either specially prepared skim milk or water or a mixture of these, and various ingredients.

The early manufacture of margarine was based on the invention of the French chemist, HIPPOLYTE MÈGE MOURIÉS, born at Draguignan, October 24th, 1817, died Paris, May 31st, 1880, who took out patents in France [1] and Britain [2], and although since then many improvements in plants and processes have been introduced the basic principles of the original invention are still applied.

The invention of margarine was the result of the search for a substitute for butter, which in the middle of the nineteenth century was produced in insufficient quantity to meet the demand consequent upon the steadily growing migration of population from country to town with change of occupation from agriculture to industry, and a general recession in farming in Europe. Butter production in overseas countries, Australia, New Zealand, Canada, etc., was still in its infancy and could not do much to relieve the shortage in Europe where butter prices soared. The situation in France was particularly difficult as regards supplies for the poorer classes of the population and the armed forces. The government there decided to invite proposals and offer a prize for a suitable substitute, which should be cheaper and keep better than butter, and MÈGE MOURIÉS, who was already engaged on the study of several important questions of national economy, was asked to tackle the problem. He won the prize, was granted his patent in July 1869 and obtained a concession to erect a plant for the manufacture of his product in Poissy, near Paris, where production commenced early in 1870, but was interrupted some months later by the outbreak of the Franco-Prussian war.

MOURIÉS's experiments were guided by the conclusions drawn from observations on production of milk by cows. When these were kept several days without food they continued to give milk, although in smaller quantities and while gradually losing body weight, but the milk still contained fat which, he inferred, could only be derived from the body fat, the tallow, of the cow. As tallow is a much harder and higher-melting fat than butter fat, he believed that through some metabolic and resorption process a fractionation of the fat took place, the softer fractions of melting point similar to butter fat being transported by the blood stream to the mammary glands in the udder, where by enzymic action it was changed into butter fat and dispersed as an emulsion in the milk plasma, while the harder fractions were used by the animal as a source of energy.

Mouriés decided to imitate the natural process by careful rendering at "animal heat", about 45 C, of fresh tallow, using artificial gastric juice in the form of extract of pig's stomach in acidified water to facilitate separation of tissue from pure fat, and submitted the purified fat to a slow crystallization process at about 25–30°C. The grainy coarse product obtained in this manner was hydraulically pressed and yielded then about 60 per cent of a soft semi-fluid yellow fraction, oleo-margarin, and about 40 per cent of a hard white fat, oleo-stearin. The softer fraction had approximately the same melting point as butter fat, had a sweet pleasant flavour not unlike melted butter fat, a pale yellow colour and could easily be plasticized. The physical similarity of this soft fraction to butter fat suggested to Mouriés that it was the butter fat in its purest form. Admittedly, the characteristic low-molecular fatty acids of ordinary butter fat were absent, but he considered these to be early degradation products caused by enzymes in the milk and the source of later rancidity development in butter. His new fat in which no deterioration had yet taken place should therefore keep better than butter fat. As regards the chemical composition of the fractions Mouriés believed that the soft part consisted of margarin and olein, the glycerides of margaric and oleic acids respectively, and the hard parts largely of the glycerides of stearic acid. The "new butter fat" was therefore called oleomargarine. In those days margaric acid was considered to be the C17 homologue of the saturated fatty acids; later it was shown that this substance which solidified in crystals with pearly lustre was a eutectic mixture of palmitic and stearic acids.

Having obtained this butter-like oleomargarine the next step was to use it for making a cream similar to that used for making butter, i.e., a dispersion of 30–35 per cent fat in milk plasma. This was done, as described by F. Boudet [3], by mixing approximately equal parts of oleomargarine, skim milk and water in a suitable mixing vessel or churn and adding a little bicarbonate of soda and 0·1–0·2 per cent of macerated fresh cows udder, as Mouriés believed it was necessary to use a little of the gland and enzyme system concerned with the formation of the milk emulsion in the cow. By agitating these constituents at the body temperature of the cow for 2–3 hours a cream emulsion was formed, which was then treated by the usual butter making process, i.e., by adding ice-cold water to the contents of the churn, which caused the emulsion to solidify in a granular mass similar to the formation of butter grains when churning butter. Most of the loose watery liquid was then drained away and the granular mass kneaded and salted by the methods normally used then for working butter.

This new product which in general composition and appearance closely resembled butter was by the inventor first described as "a variety of true butter taken at its source", later as "artificial" butter or Butterine and finally as Margarine.

As the production increased in France after the Franco-Prussian war an enquiry into the merits of the product was undertaken by the Council of Hygiene in Paris, probably because of frequent adulteration of butter with the artificial butter. The result of the enquiry was favourable to the new manufacture and the Council issued a decree of April 12th, 1872, permitting manufacture and sale of MÈGE MOURIÉS' new artificial butter, provided it was not described as butter. A public company, *Societé Anonyme d'Alimentation*, was formed to exploit the new process.

DEVELOPMENTS

In the meantime the MÈGE MOURIÉS' process had been acquired for Holland in November 1871 by the firm *A. Jurgens* in Oss, and in course of a few years the manufacture of margarine was taken up in a number of countries, Austria 1873–1874, Italy 1874, Germany probably 1874. MOURIÉS' American patent was granted in December 1873 and renewed in 1874; this was acquired by the *United States Dairy Company* who took up the manufacture there. In Norway the manufacture dates back to 1876 and in Denmark, which later became the largest *pro-capita* consumer, to 1883. Since then the manufacture has spread to most countries. For many years some countries; for example Canada and the Union of South Africa, prohibited the manufacture or sale of margarine, in the alleged interest of dairy industries, but during the last decade the regulations there have been changed and factories commenced to operate. The name Margarine has now been accepted in most countries as the correct designation, but a number of descriptions have been used in the past, such as Artificial Butter, Kunstbutter, Sparbutter, Vegetable Butter, Butterine, etc. In United States it was known for many years as Butterine, later officially as Oleomargarine, but the name Margarine is generally used now. In Britain it was called Butterine till the Margarine Act of 1887 made the name Margarine compulsory.

Soon after the introduction on the market of MOURIÉS' product various modifications in the process were patented by several inventors, but they did not change the basic principles, namely the preparation of an appropriate fat and the mixing of this with milk to form a cream-like emulsion. PELLERIN fils and JULIEN [4], using MOURIÉS' method for preparing the fat, plasticized this and kneaded into the plastic fat an emulsion such as milk or a vegetable emulsion such as almond milk. ROUDEBUSH in U.S.A. [5] used the carefully prepared beef fat, softened it by adding oil, such as cottonseed oil, and churned the melted fat mixture with fresh or sour milk or cream. DIDERICHSEN [6] used bicarbonate of soda in the preparation of the beef fat and also some liquid oil for softening the fat; the melted mixture was then churned with butter milk, the emulsion solidified and kneaded in cold water, salted and treated as butter. D. **Hipkins** [7] claimed improvements in the preparation of the fat by washing it in water containing salt and a little acetic acid. **Dordron**, **Villeron** and **Beyinge** [8] also used liquid oil, 5–10 per cent, as addition to the fat and a high proportion of milk, 70–75 per cent. **Mège Mouriés** himself improved his process, as described in an additional French patent in May 1874, and a British patent, 1877 [9]. In this he used for the separation of the beef fat from the tissue not only the macerated sheeps' stomach as in his original patent, but also some hydrochloric acid and biphosphate of lime as an artificial gastric juice. Crystallization for fractionation was at 25–30°C and churning at 20–22°C with 12–20 per cent cream containing 0·1 per cent bicarbonate and some macerated udder. The emulsion was formed in course of about one hour. Milk and butter could be used in place of cream. The emulsion was poured into a vessel with cold water for rapid crystallization, the solidified mass rolled and kneaded. The milk or cream was soon considered to contain the same emulsifying principle as the mammary glands of the udder, and the use of the latter was abandoned.

As the selection of the basic fat for margarine was the result of association with dairy farming, so was the sequence of treatments by which the fat was made into margarine; the plant and the methods adopted were those of the dairy. But while the comparatively simple plant was suitable for the small scale on which butter was then made, the rapid development of margarine manufacture to an industry of considerable magnitude necessitated the introduction of new and more rational plant as well as a wider range of suitable fatty materials. The production of beef fats increased rapidly, particularly in America, but could hardly keep pace with the expansion of the margarine industry in Europe. Although oleomargarine—in America called oleo-oil—remained the most important raw material until well into this century, other solid fats used in minor proportions in the earlier days were lard and carefully rendered fresh unfractionated beef suet, in Europe called "Premier jus", in America "Oleo-stock". To adjust the melting point of the fat-blend to climatic conditions liquid oils such as groundnut oil, olive oil and sesamé oil were taken into use. A margarine fat-blend might for example consist of about 70 per cent oleomargarine, 10 per cent premier jus and 20 per cent liquid oil.

When towards the end of the nineteenth century the technique of refining fats and oils was developed, further fatty raw materials, cottonseed oil, corn oil, coconut oil and palmkernel oil were taken into use and helped to relieve the shortage and price increase of the animal fats, particularly oleomargarine, and about 1907 the vegetable fatty materials formed 25–30 per cent of the fat-blend in Europe. As the price curve for oleomargarine rose very steeply in the following years, the European margarine manufacturers who were responsible for by far the largest share of the production began to rely more and more on vegetable fats and oils, and just before the first world war these accounted for more than 80 per cent of the fatty raw materials, of which coconut oil and palmkernel oil formed about 60–65 per cent.

The comparatively low melting points of coconut oil and palmkernel oil, 24–28°C, combined with their rather hard consistency, which necessitated the use of a certain proportion of liquid oil with them, made their use in warm weather rather difficult, and it was therefore of the utmost benefit to the margarine industry when hydrogenation of oils made it possible to obtain from the ample and relatively cheap sources of liquid and marine animal oils a range of fats of any desired degree of firmness for edible use. The margarine manufacturers thus became practically independent of the beef fat and lard market and could in their fat-blends compensate for the relatively low melting points of the otherwise excellent vegetable fats and oils. The first edible hydrogenated fats appeared on the market 1912–1913 and have since increased rapidly in usage until the present day, when they are probably the most important fatty raw materials.

Other important fats which the developing refining industry has made available are palm oil, soyabean oil, sunflower oil and several others.

The other principal raw material in MÈGE MOURIÉS' process was milk, or a mixture of milk and water. It was used partly as an emulsifying medium for dispersing the fat, partly to give a creamy butter flavour to the product, and the proportion was at least equal to that of the fat. As the knowledge of flavour development by controlled ripening of the milk increased, particularly after the introduction of selected bacterial cultures for ripening cream for butter making, the margarine industry adopted this method for ripening the milk, and by improving ripening and emulsification techniques gradually reduced the proportion of milk and aqueous phase required, until it reached the theoretical amount to ensure the final moisture content in the margarine.

A continuous improvement has also taken place in connection with plant and processes. Better churns and emulsifying devices were introduced and instead of solidifying the emulsion by pouring large quantities of ice-water into the churns, the emulsion was run into large basins of ice-water from which the solidified grainy mass was skimmed off. L. Q. BRIN, Paris, patented [10] a number of improvements on the earlier type of plant, for example treatment of the materials in vessels under exclusion of air, solidification by spraying the emulsion into cold water through a nozzle fixed at the bottom of the water tank, and better stirring and temperature control so that the use of chemicals for emulsification and other purposes could be discarded. Later, when refrigeration machinery made possible the supply of large quantities of water cooled to a constant temperature of 1–3°C, the emulsion was solidified by spraying it with a douche of such water which was removed from the collecting trucks by draining. These wet cooling methods were, however, wasteful in refrigeration—the water could not be re-used without danger of bacterial infection—and in materials, as some fat and much milk was washed away. It was therefore a great step forward when "dry" cooling and solidification was introduced in 1907 by spreading the emulsion on refrigerated steel rollers or drums, initially cooled by brine circulation, later by direct ammonia expansion (1928).

Kneading or working of the solidified grainy product for plasticizing and removal of excess water was originally done on horizontal revolving circular tables with fluted wooden rollers as developed a few years earlier in America in the butter factories. This type of kneading machine, though much improved mechanically, is still in use in some factories. Later more elaborate rolling machinery was designed with two, three or more pairs of rollers made of wood, granite or stainless steel. When the importance of avoiding excessive exposure to and incorporation of air was realised, closed kneading machines working under vacuum were introduced. Packing and wrapping which for many years was a manual operation became mechanized about 30 years ago, and since then highly efficient and economic plant has gradually been evolved.

For many years the manufacture of margarine was done on the "batch" principle, and this is still the system used in many factories. Definite quantities were churned for half to one hour, and after cooling the product was rested for a period prior to kneading and between repeated kneadings. About 1925 "continuous" plants began to make their appearance in the margarine factories, but it took some years before they were successfully established. In these plants the various steps of emulsification, solidification and plasticizing by kneading followed in continuous sequence; until quite recently a short rest of the product has been customary between plasticizing and packing by automatic machinery. The continuous process has been further developed during the last ten years in certain plant constructions, where emulsification, cooling and plasticizing is combined in one plant which under certain conditions supplies the margarine ready for immediate packing by mechanical plant.

NUTRITIONAL ASPECTS

The quest for a substitute for butter which led to the invention of margarine implied that it should not only resemble butter in appearance and physical character, but should also, if possible, be of equivalent nutritive value. In those days nutrition science was in its infancy and the nutritive value of a food was assessed on its "nutritive constituents", proteins, carbohydrates, fats and minerals. Chemical tests indicated the quantities in which these were present, physical tests their heat or calorific value and physiological tests their digestibility or absorbability, i.e., the completeness with which they were retained in the body and utilized by metabolic processes.

As margarine contained the same nutritive constituents, so far as then known, as butter and in the same proportions, and as the fats and oils used were those normally used in the human food, it was generally assumed that the margarine fulfilled its rôle as a nutritive equal of butter. Physiological tests were not as searching as now, and those which were done in various countries, where dairy interests viewed the new product with suspicion, confirmed the belief that the difference in food value between butter and margarine was insignificant. JOLLES [11] came to this conclusion from tests on dogs when he found butter and margarine utilized to the extent of 97–98 per cent. LURIG [12] in Germany and HULTGREN and LANDERGREN [13] in Sweden came to similar results.

It had been observed that though the calorific values of butter fat and the fats and oils used for margarine were very similar the digestibility of the fat was to some extent related to its melting point. This varied within narrow limits in butter fat, but was always 5–10°C below the human body temperature, whereas the melting point of margarine varied with its fat-blend composition, and some of the fats used in the blends, for example premier jus, melted well above the body temperature. ARNSCHRINK [14] recorded one of the earlier investigations and found that fats and oils melting below body temperature, had digestibility coefficients of 97–98 per cent, fats melting slightly above body temperature had coefficients of 89–93 per cent and very hard fats with melting point of 50°C or more had coefficients of 86–91 per cent.

The introduction of hydrogenated fats in the margarine industry and the possibility of using a wide series of new fats ranging in melting points from those of the natural fats and oils to fully hydrogenated fat of 60–65°C melting point made it desirable to test the digestibility and wholesomeness of the individual fats as well as the margarines made from them. Among the best known investigations are those done under the auspices of "Office of Home Economics" in Washington by LANGWORTHY, HOLMES and DEUEL and published in a series of bulletins and papers [15] [16] [17] [18]. A summary of LANGWORTHY and HOLMES' results is shown in the table below and also in an American publication [19].

ERLANDSEN, FRIDERICIA and ELGSTRÖM in Denmark [20] studied the digestibility of hydrogenated whale oil by itself and in mixtures with other fats in margarine blends and found from these tests on humans, that the hydrogenated whale oil and the butter fat had the same coefficients of digestibility and that in prolonged tests on a large number of humans, when consuming a margarine in which one-third of the fat was hydrogenated whale oil, no unfavourable effect could be observed from the use of hydrogenated fat.

Since these experiments were made, many similar ones have been conducted with improved experimental technique in scientific institutions and in private research laboratories in many parts of the world. While many of these tests were on animals confirmation of the results have been obtained on humans. Careful statistical analyses of these results show that the evidence from the tests on adult humans correlate well with those from the usual experimental animals such as rats and dogs. ROY, at the University of Calcutta [21] when testing on rats a number of Indian fats and oils as well as some hydrogenated fats found digestibility coefficients 95·5–99·5 per cent. DEUEL, at the University of Southern California [22], has carried out numerous tests on animals

TABLE I.—*Digestibility Coefficients of Fats and Oils*

Material	*Melting point (°C)*	*Digestibility coefficient (per cent)*
Butter fat	about 30	96·9–97·1
Lard	36–40	97·3–98·4
Mutton tallow	46–48	87·6–88
Beef tallow	44–46	93·1
Oleomargarine	30	96·8
Oleostearine	49–54	80·1–93·5
Soyabean oil	liquid	97·5
Sunflower oil	,,	96·5
Maize oil	,,	96·8
Cottonseed oil	,,	97·8
Groundnut oil	,,	98·3
Palmkernel oil	28	98·0
Coconut oil	24	97·9
Mixed hydrogenated fat	41·3	96·6
Hydrogenated groundnut oil	37	98·1
,, ,,	39	95·9
,, ,,	50	92

and human subjects and found for the fats of margarine blends and for butter fat average digestibility coefficients of about 97 per cent. Analogous results have been found in food research laboratories in Britain, Sweden, Holland and other countries, and it is generally accepted that the fats and oils, animal, vegetable and hydrogenated, normally used for margarine blends have similar and high coefficients of digestibility, 95 per cent or more, as long as the melting point does not exceed the body temperature by more than a few degrees, say 40–42°C.

Although fats may have similar coefficients of digestibility, some may show difference in the rate of absorption; for example, rape oil and hydrogenated rape oil have been found to be absorbed at a slower rate than most other oils and fats of similar melting points. This may be connected with the fatty acid and glyceride composition, and the rapidly increasing knowledge of the glyceride composition of fats and oils, natural and hydrogenated, will no doubt help to throw more light on the subject of fat absorption from the intestinal lumen into the lymphatic and blood streams of the body. What is described as the melitng point of the fat is in fact the "combined melting point", ascertain by a standardized procedure, of a mixture of glycerides of different melting points. The melting point of a fat may, for example, be 40 C and it may contain proportions of the high-melting saturated glycerides such as palmitins and stearins with melting points of 60–70 C. The low digestibility and slow rate of absorption of some fats is now widely held to be related to their content of such high-melting glycerides.

In the manufacture of margarine, however, fats are used which contain none, or only very small proportions, of these glycerides. Most natural fats have their fatty acids combined with glycerol in accordance with the rule of even distribution, and their glycerides have therefore melting points below, or only slightly above, body temperature as mixed saturated-unsaturated glycerides melting below 42°C. Exceptions are found among certain animal fats, such as mutton and beef tallows, which are the fats showing relatively low coefficients of digestibility. They contain, as will be shown later under Raw Materials (page 24) about 20 per cent fully saturated glycerides which have individual melting points above 60°C. A fully saturated fat, such as completely hydrogenated sunflower oil, containing practically only saturated glycerides of C16 and C18 acids and having a melting point of *ca.* 68°C, has in recent experiments shown a digestibility coefficient of *ca.* 25 per cent, but such a fat is not used for margarine. This recent work has shown a distinct falling off in digestibility when higher-molecular fully saturated fats than tripalmitin are consumed, and they have also shown indications that the position of the stearic acid radical in the glyceride molecule affects the digestibility [23].

According to earlier views on the breakdown of fats in the alimentary system to glycerol and fatty acids by the action of fat-splitting enzymes, there would be present in the intestines a proportion of high-melting fatty matter, depending upon the percentage of saturated fatty acids with fourteen or more carbon atoms which the fat contained. Later theories, put forward by FRAZER [24] [25] [26] [27], suggest that only about 30 per cent of the fatty acids are liberated and these with partly hydrolized glycerides, such as mono- and diglycerides, and bile salts create the emulsification conditions which will effect an extremely fine dispersion of the non-hydrolized 70 per cent of the glycerides and cause these to pass into the intestinal cells for absorption. Hence, though a fat may contain a fairly high proportion of high-melting fatty acids these would be combined with low-melting or liquid acids in the glyceride molecules and the fat would be liquid or semi-liquid at body temperature. This theory would appear to explain why fats with fairly high percentages of high-melting fatty acids in the glyceride molecules show high digestibility and rate of absorption.

The old criteria of nutritive value, i.e., calorific value and digestibility, were found insufficient to evaluate the relative values of butter and margarine when vitamins were discovered as essential food factors and gave rise to the modern science of nutrition. The publications by FREDERIC GOWLAND HOPKINS, CASIMIR FUNK and other pioneers in nutrition started a new approach and adoption of new techniques based on growth effects and health of the experimental animals. In searches for food which contained these essential, but then vaguely defined substances T. B. OSBORNE, L. B. MENDEL, E. V. MCCOLLUM and M. DAVIS in U.S.A. found, and recorded in various publications, that butter contained a growth-factor, whereas this was absent in lard. MCCOLLUM and DAVIS [28] found that it was present in the unsaponifiable fraction of butter fat and they succeeded in transferring it to olive oil. These workers stated in 1915 that there were several growth factors, and for that soluble in fat they suggested the designation "Fat-soluble A".

The new knowledge that was emerging, showing that butter contained fat-soluble A, whereas other accepted food fats such as lard and olive oil were deficient, made some margarine manufacturers reconsider the question of the relative food values of margarine and butter, particularly when a paper published by HALLIBURTON and DRUMMOND [29] showed that by the methods of testing then employed margarines, particularly vegetable margarine, were devoid or deficient in fat-soluble A. Progress in the study of fat-soluble vitamins was slow, partly because of the protracted nature of feeding tests which were the only ones then available for ascertaining whether vitamins were present, partly because the nature and stability of vitamins were largely unknown. More rapid progress was made when in the early twenties it was realised that two factors were involved in the fat-soluble A effect; they came to be known as the growth-promoting vitamin A and the anti-rachitic vitamin D.

Much knowledge was now accumulated about the contents in all relevant fats and oils of these vitamins, better and more precise methods of assay were evolved and the behaviour of these vitamins under processing treatment was ascertained. While butter fat, though varying in vitamin content with seasons, breed of cattle and conditions of feeding, was found to be a good source, practically all fats and oils used for margarine, particularly when refined to edible standard, were devoid of vitamins A and D. To remedy this defect consideration was given to the possibility of refining the only known, but strongly flavoured rich sources, the liver oils, or of extracting the vitamins from them and transferring them to the margarine fats without affecting unfavourably the flavour of the latter. By these methods it was found possible to obtain concentrates of vitamins A and D suitable for additions to margarine fats, and vitaminized margarines began to be marketed. In some countries the standard for vitamin content was that of good butter and this was achieved and proved by assays on animals [30]. New and very rich sources of vitamins A and D were found in the liver oils of tunny and halibut and for vitamin A in whale and shark liver oils. The discovery by STEENBOCK that sterols on exposure to ultraviolet radiations could acquire vitamin D potency led to the production of irradiated ergosterol of standardized potency, and later to a pure vitamin D product, calciferol, in crystalline form. International standards for vitamin potency were introduced, and with these available and with independent sources of the two vitamins it was possible to impart to margarine a constant potency and at a level which was generally decided in relation to that of butter. The latter, when tested against the international standards, was found to vary widely as the result of breed of cattle, season of the year, lactation and feeding. Vitamin A potencies of 3–60 i.u.p.g. (international units per gram) and vitamin D potencies of 0·1–4 i.u.p.g. were recorded. A good average accepted by many nutritionists was 20 units A and 1 unit D per gram.

Of quite recent date is the introduction of synthetic vitamin A in the form of vitamin A acetate or palmitate, which has been found nutritionally equivalent to the vitamin A ester from liver oils. A vitamin D product obtained by irradiation of 7-dehydrocholesterol and termed vitamin D_3 or cholecalciferol is used in some cases in place of the vegetable product calciferol, now usually termed vitamin D_2 or ergo-calciferol. Various β-carotene preparations are also used as source of vitamin A potency, but the amount that can be used is limited by the strong colouring effect of carotene. (See also page 107.)

Many margarine manufacturers voluntarily undertook to vitaminize, or fortify, their products, but in some countries vitaminization was made compulsory by statute. In Great Britain the vitamin potency has for several years been 19·3 units A and 3 units D per gram, in U.S.A. it was first 16 i.u.p.g. A, corresponding to 20 U.S.P. units, but has recently been increased to about 26–28 i.u.p.g.; no vitamin D is compulsory. In the Union of South Africa the statutory potency is 20 i.u.p.g. A and 1 unit D. Other countries have other standards, but generally it can be said, that when adequately vitaminized margarines are compared in animal and human feeding tests with butter, the results justify the claim that the two products are of equal nutritional value.

Apart from vitamins A and D, fats are also vehicles for the later discovered fat-soluble vitamins E and K.

Vitamin E or alpha-tocopherol is present in most vegetable fats, but only in traces in animal fats. In addition to its vitamin effect is has also antioxidant properties which give vegetable fats better resistance than animal fats against oxidation.

Neither butter nor margarine seem to be significant sources of vitamin K, the importance of which for man is doubtful, but the vitamin K in animals probably passes into the system through its solubility in fat in the intestines.

Burr and Burr [31] showed that for animals certain unsaturated fatty acids are essential for growth and health. These acids are linoleic, linolenic and arachidonic acids and are present in most of the oils used in margarine blends, and generally in larger proportions than in butterfat; their significance for humans is uncertain.

Since chemical and physical tests were developed some years ago which permit the quantitative determination of the vitamin content of butter and margarine with a high degree of accuracy, numerous experiments both on humans and animals have been made on these fatty foods of equal vitamin contents to compare their nutritional values in adequate diets in which the only variant is the actual fat. These tests have shown that the margarine can satisfactorily be used as an alternative to butter. Some of these investigations have, when done on rats as experimental animals, been extended over several years, covering a number of generations, and show not only the direct dietetic effect, but also search for possible influence on reproduction. Among the published results may be mentioned those by H. J. Deuel and his collaborators in U.S.A. [32] [33] [34] [35] [36], HENRY, KON *et al.* in Britain [37], EULER, EULER and SÄBERG in Sweden [38] [39] [40], SMITH in Britain [41] and SMITS in Holland [42].

From time to time reports have been published of experiments which tend to show that butter fat contains some specific nutritional factor not present in other fats. Some workers have described it as a long-chain saturated acid, others as an unsaturated acid, vaccenic acid, others again as a hitherto undefined compound. It has also been stated that in certain ill-balanced and deficient diets butter fat has a higher nutritional effect than the equivalent amount of other fats. Professor H. J. DEUEL, of School of Medicine, University of Southern California, has dealt with these controversial views in a paper, entitled "The Butter-Margarine Controversy" [43]. That the glycerides of butter fat should possess some special nutritional virtue for humans seems difficult to accept in view of the fact, as shown by various workers, for example HILDITCH and MEARA [44] and BALDWIN and LONGENECKER [45], that the fat of human milk, the ideal fat for the human young, is very different from the fat of cows milk and more similar to that of a margarine fat-blend.

The question has often been raised whether there is a physiological minimum or an optimal amount of fat required in human nutrition. In spite of many detailed studies of this problem during wartime rationing of essential foods no clear-cut answer has been obtained. Daily intakes of 15–20 grams have enabled good health to be maintained, at any rate for some years, but it is generally accepted as desirable that the daily intake of fat should provide 25–30 per cent of the required caloric need, i.e., from 50–130 grams fat per day, according to occupation.

The fat intake includes fat from all dietary sources and not only from those commonly classified as "fatty foods", namely butter, margarine, lard, suet, etc. These foods which contain 80–100 per cent fat in their composition are not consumed separately, but in mixtures with carbohydrate and protein-containing foods, bread, meat, cakes, vegetables, etc., and an important nutritional function of fat is that of making food preparations in which it is used more palatable and of improved flavour, and of helping to regulate and delay gastric evacuation time, thus giving to food a more "sustaining" value; it further functions as a solvent for the absorption of fat-soluble vitamins. Although in theory extra carbohydrate in the diet can compensate for shortage of fat, in practice it is only possible to a limited extent. In warm climates where the diet is frequently very rich in carbohydrates, fat is needed as an aid to the digestion of cereals; in arctic climates where rich meat is consumed extra fat is required as a source of heat. Fat provides, weight for weight, 2¼ times as much energy or heat value as carbohydrates and protein.

The scientific literature records numerous experiments to study differences in nutritional value of the various fatty acids and their glycerides, and occasionally it is found that on special ill-balanced diets an individual fat may be less satisfactory than another, but where in the extensive investigations in many countries, to which reference has been made, natural fats or mixed fats of wide glyceride composition have been studied, the fats *per se* have shown no significant difference. All these fats from natural sources are glycerol esters of fatty acids of different chain length and degree of saturation, but all with an even number of carbon atoms. In recent years synthetic fatty acids, made by catalytic oxidation of hydrocarbons from various sources, have been esterified with natural or synthetic glycerol and thus formed synthetic fats; the fatty acids have been found to include a high proportion with an odd number of carbon atoms, which do not appear to be metabolized in the same way as the even numbered. Feeding tests on animals with these synthetic fats have thrown some doubt on their nutritional value in comparison with natural fats, although they are of value for diabetics. (See also page 46.)

Hydrogenated fats are sometimes described as synthetic fats, as they are not found in nature. Feeding tests both on animals and humans have, however, always shown them to be as well utilized in the body as natural fats of similar melting point and glyceride composition. Recent tests with such fats, in which labelled hydrogen, deuterium, has been used instead of ordinary hydrogen for hydrogenation, have enabled physiologists to follow the metabolism of these fats and have confirmed their satisfactory nutritive value.

Although the measurable criteria for nutritive value, such as digestibility, energy value, protein composition, vitamin content, etc., may be satisfactory, the psychological effect of flavour, palatability and attractiveness of a food must be taken into consideration. This factor is however related to food habits, individual preferences, and traditions, and universal standards cannot be applied. It has been demonstrated frequently in practice both on humans and on animals. H. J. Deuel showed in experiments with rats how food-intake, and thus growth response, is influenced by flavour [46].

Fatty foods are very rarely consumed as consisting of 100 per cent fat. The fat is generally well dispersed and mixed with other food components, either naturally as in milk, eggs, meat, beans, nuts, etc., or in food preparations such as cakes, biscuits, cheese, etc. Where it is offered for consumption without thorough mixing with other foods, as for example for salads or with bread, it is preferably used as an emulsion such as salad cream, mayonnaise or butter. Whereas salad cream and mayonnaise are manufactured emulsions, butter may be considered a natural emulsion as the result of its being derived from milk and cream emulsions, although the system of dispersion has largely changed.

When considering a substitute for butter it was therefore logical that the inventor should aim at a product of similar solid emulsion form as butter. This has a two-fold object. Firstly, the taste- and odourless refined fats are emulsified with an aqueous solution, usually skim milk, which has been prepared by ripening or by the addition of suitable flavour compounds, to impart to the final product a flavour similar to that of butter. Although the fat to some extent acts as a fixative for the flavour, most of this resides in the aqueous phase, and it is the contact of this with the taste papillae of the tongue which distinguishes the emulsified food from the pure fat. Secondly, the state of emulsion helps to give the fatty food some of the desirable characteristics associated with plasticity, "spreadability" and general suitability for preparation of foods by frying or by acting as a shortening. Other factors play a part, such as the physical properties of the oils and fats used, their crystalline condition, etc., but the emulsion makes an important contribution. Whether nutritionally the emulsified product is superior to the pure fat is uncertain. In most feeding tests the fat has been administered in intimate mixture with other ingredients or dispersed as fat in an artificial milk, but in some tests, where the fat-component has been given separately, but on equi-caloric basis, little difference has been found, and such small differences as noticed may be due more to psychological than physiological reasons. When ingested the fat soon comes under the influence of the gastric secretions and is ultimately absorbed from the intestinal tract as an emulsion.

STATISTICS

Margarine is therefore today, as when first introduced, made by emulsifying refined and prepared oil-fat blends with an aqueous phase, usually skim milk, solidifying by rapid chilling, and plasticizing the solidified product. The industry has grown to a very important one and production is carried out in units of widely varying capacities. Factories with output of the order of 5–10 tons weekly and localized distribution operate successfully in some countries, whereas in others production is largely in big factories, some with outputs of 1500–2500 tons per week. The following tables give an indication of the magnitude of the industry at different periods in a number of countries.

In addition to the countries shown in Table II many others have a margarine production, sometimes of types to suit local climates and conditions, sometimes made for special culinary purposes. In pre-war days important production of margarine took place also in Russia, Poland, Czechoslovakia, Austria and Hungary. Factories operate also in Switzerland, Portugal, Turkey, Israel, Indonesia, Thailand, Philippines, China, Mexico and several South American countries. In India and Pakistan there is a production of about 180,000 tons per annum of the local type of substitute for Indian butter, ghee, often referred to as "Vegetable Ghee", officially called Vanaspati in India; this is however—as is also ghee—a 100 per cent fatty product.

The total margarine produced in the countries in Table II was:

1950 . . .	1,775,000 tons
1951 . . .	2,033,000 ,,

For comparison, to show the magnitude of the margarine industry, Table III gives the butter production for the same countries, including New Zealand and excluding South Africa, in pre-war years and for 1950 and 1951.

In India and Pakistan there is a production of the local type of butter fat—ghee—to the extent of about 600,000 tons per annum and in many other countries local production of some magnitude, for example in Eire 55,000

TABLE II.—*Production of Margarine in Metric Tons*

	1913	1929	1934	1938	1950	1951
United Kingdom .	85,000[1]	203,000	168,000	217,000	379,000	453,000
Holland .	88,000[1]	133,000[1]	58,000	64,000	176,000	180,000
Belgium .	10,000	49,000	40,000	61,000	65,000	69,000
France .	15,000	35,000	30,000	32,000	60,000[2]	60,000[2]
Germany .	225,000	437,000	400,000	397,000	364,000[3]	473,000[3]
Denmark .	42,000	79,000	72,000	81,000	61,000	73,000
Norway .	27,000	47,000	50,000	55,000	68,000	75,000
Sweden .	24,000	55,000	53,000	59,000	83,000	86,000
Finland .	1,000	10,000	—	14,000	16,000	18,000
U.S.A. .	69,000	162,000	120,000	175,000	425,000[4]	470,000[4]
Canada .	—[5]	—[5]	—[5]	—[5]	43,000[6]	48,000[6]
Australia .	—	—[7]	—	15,000	30,000	25,000
South Africa	—[8]	—[8]	—[8]	—[8]	5,000[9]	3,000[9]
				1,170,000	1,775,000	2,033,000

[1] Considerable export from Holland to United Kingdom.
[2] Estimated, includes confectionery fats of margarine type.
[3] Western zone of Germany only.
[4] Margarine regulations liberalized.
[5] Manufacture prohibited till 1949.
[6] New regulations in force.
[7] Only confectionery type of margarine permitted.
[8] Manufacture prohibited.
[9] Limited manufacture under licence introduced at end of war.

TABLE III.—*Butter Production in Metric Tons*

	Pre-war	1950	1951
United Kingdom	46,000	25,000	15,000
Holland	102,000	93,000	84,000
Belgium	64,000	78,000	75,000
France	245,000	250,000	250,000
Germany	508,000	269,000	286,000
Denmark	189,000	179,000	168,000
Norway	15,000	20,000	19,000
Sweden	100,000	111,000	108,000
Finland	33,000	45,000	54,000
U.S.A.	1,016,000	752,000	656,000
Canada	163,000	141,000	137,000
Australia	196,000	177,000	148,000
New Zealand	171,000	174,000	190,000
	2,848,000	2,314,000	2,192,000

60,000 tons per annum, in Switzerland 20,000–25,000 tons per annum, in South Africa, Argentina, Austria, as well as in Russia and adjacent countries, but generally speaking the margarine productions has become of the same order as butter production.

While margarine during the last 20 years has been made mainly for local consumption, butter is in certain countries made with a large surplus for export, for example Denmark, Sweden, Australia and New Zealand, and consumption figures differ from production figures. As butter has been rationed in many countries during and for some years after the war, consumption comparison of butter and margarine during that period is on an artificial basis. Table IV gives comparative consumption figures for margarine and butter in some countries for some pre-war years.

Table IV.—*Consumption of Margarine and Butter in Metric Tons*

	1934		1936		1938	
	Margarine	*Butter*	*Margarine*	*Butter*	*Margarine*	*Butter*
United Kingdom	168,000	539,000	179,000	537,000	217,000	519,000
Holland . .	58,000	47,000	53,000	45,000	64,000	49,000
Belgium . .	40,000	81,000	52,000	69,000	61,000	63,000
France . .	30,000	217,000	29,000	252,000	32,000	243,000
	1934		1935		1936	
Germany . .	400,000	485,000	445,000	572,000	397,000	606,000
Denmark . .	72,000	33,000	78,000	34,000	81,000	29,000
Norway . .	50,000	15,000	55,000	15,000	55,000	—
Sweden . .	53,000	53,000	56,000	67,000	59,000	72,000
U.S.A. . .	120,000	1,033,000	178,000	967,000	175,000	1,001,000

The increase in margarine consumption per head of population in the same countries over a number of years is shown in Table V as pounds per head per annum.

Table V.—*Annual per Capita Consumption of Margarine in lbs.*

	1913	1924	1934	1938	1950	1951
United Kingdom .	7·76	11·77	8·0	10·0	16·7	19·9
Holland . . .	4·4	15·7	15·2	16·0	37·6	38·4
Belgium . . .	3·32	7·42	10·3	15·4	16·7	18·8
France . . .	0·9	1·54	1·6	1·7	3·1	3·1
Germany . . .	7·93	12·34	13·3	12·8	16·0	20·8
Denmark . . .	33·0	45·6	43·2	47·3	31·2	37·4
Norway . . .	24·0	35·3	38·1	41·5	45·3	50·0
Sweden . . .	9·9	12·3	18·7	20·5	26·0	27·0
U.S.A. . . .	1·58	2·05	2·1	3·0	6·1	6·7

II. RAW MATERIALS

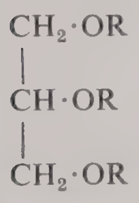
Fats and Oils

1. THEIR CHEMISTRY

To understand some of the fundamental considerations, which are applied in selecting oils and fats for the fat-blends used for margarine, it is necessary to have some knowledge of the chemistry of the glycerides, the oils and fats. This has increased rapidly during the last thirty years, and for detailed information the reader is referred to specialist works on the subject [47] [48] [49] [50] and others. For this book the following summary should suffice.

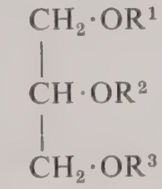
The fats and oils with which we are here concerned are all esters of the trihydric alcohol glycerol, $C_3H_5(OH)_3$, and fatty acids. If all the OH-groups are esterified a triglyceride is formed, if two are esterified a diglyceride and if one a monoglyceride. Natural fats and oils are almost entirely triglycerides; a small proportion of mono- and diglycerides together with some free fatty acids is found as the result of incipient degradation by enzymic hydrolysis in crude fats, and a small proportion, usually less than 0·5 per cent, of a mono-diglyceride mixture is often added during the margarine manufacturing process to impart certain physico-chemical properties to the product (see page 133).

The triglycerides can be esters of one particular fatty acid, in which case they are simple triglycerides, $C_3H_5(OR)_3$, or of two or three different fatty acids, when they are termed mixed triglycerides, for example $C_3H_5\cdot OR^1\cdot OR^2\cdot OR^2$ or $C_3H_5\cdot OR^1\cdot OR^2\cdot OR^3$, where R stands for the fatty acid radical. Usually the formulae for the various types of glycerides are shown as follows:



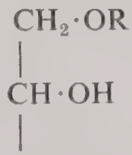
$$\begin{array}{l} CH_2\cdot OR \\ | \\ CH\cdot OR \\ | \\ CH_2\cdot OR \end{array}$$

Simple triglyceride.



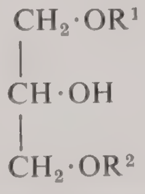
$$\begin{array}{l} CH_2\cdot OR^1 \\ | \\ CH\cdot OR^2 \\ | \\ CH_2\cdot OR^3 \end{array}$$

Mixed triglyceride.



$$\begin{array}{l} CH_2\cdot OR \\ | \\ CH\cdot OH \\ | \\ CH_2\cdot OH \end{array}$$

Monoglyceride.



$$\begin{array}{l} CH_2\cdot OR^1 \\ | \\ CH\cdot OH \\ | \\ CH_2\cdot OR^2 \end{array}$$

Mixed diglyceride.

The fatty acids in natural fats are, with one of two exceptions, straight-chain compounds of carbon atoms linked together by single linkages in the saturated acids while one or more double linkages occur in the unsaturated acids. Each carbon atom, except the terminal ones, in the saturated acids combines with two hydrogen atoms; in the unsaturated acids the carbon atoms which are linked by double bonds connect with only one carbon atom each. The number of carbon atoms vary from 4 to 24 or more, but most acids have between 12 and 22, and in natural fats the number is, with very rare exceptions, even, whereas some recently produced synthetic fatty acids have also an uneven number of carbon atoms. The formula for a saturated acid, for example stearic acid with 18 carbon atoms, C_{18} acid, is usually written as: $CH_3 \cdot (CH_2)_{16} \cdot COOH$, or in shorter form $C_{17}H_{35} \cdot COOH$.

Similarly the mono-unsaturated or mono-ethenoid C_{18} acid, oleic acid, with one double bond has the formula $CH_3 - (CH_2)_7 - CH = CH - (CH_2)_7 - COOH$.

The di-unsaturated or di-ethenoid C18 acid, linoleic acid, with two double bonds has by the same system the formula $CH_3 \quad (CH_2)_4 - CH = CH - CH_2 - CH - CH - (CH_2)_7 \quad COOH$, and the tri-unsaturated or tri-ethenoid C18 acid, linolenic acid, with three double bonds the formula $CH_3 - CH_2 - CH = CH - CH_2 - CH = CH - CH_2 - CH = CH - (CH_2)_7 - COOH$.

The saturated acids from C10 and upwards are solid; the more common unsaturated acids are liquid, with the exception of some isomers of oleic and linoleic acid, mostly formed in course of hydrogenation, and the mono-unsaturated C22 erucic acid.

Table VI shows the usual names, systematic names, number of carbon

TABLE VI

Name	*Systematic Name*	*C Atoms and Code Nomenclature*	*No. of Double Bonds*	*m.p., °C*
Butyric	Tetranoic	C4	—	−7·9 liquid
Caproic	Hexanoic	C6	—	−3·4 liquid
Caprylic	Octanoic	C8	—	16·7
Capric	Decanoic	C10	—	31·2
Lauric	Dodecanoic	C12	—	44·2
Myristic	Tetradecanoic	C14	—	54·4
Palmitic	Hexadecanoic	C16	—	62·9
Stearic	Octadecanoic	C18	—	69·6
Arachidic	Eicosanoic	C20	—	74·4
Behenic	Docosanoic	C22	—	79·7
Lignoceric	Tetracosanoic	C24	—	84·2
Myristoleic	Tetradecenoic	C′14	1	liquid
Palmeitoelic	Hexadecenoic	C′16	1	0·5 liquid
Oleic	Octadecenoic	C′18	1	16·2
Iso-oleic acids	—	C′18	1	34–44
Erucic	Docosenoic	C′22	1	34
Linoleic	Octadecadienoic	C″18	2	−6 liquid
Linolenic	Octadecatrienoic	C‴18	3	−11·5 ..
Arachidonic	Eicosatretraenoic	C′′′′20	4	−50 ..
Clupanodonic acids	Eicosapentaenoic	C′′′′′20	5	..
	Docosatetraenoic	C′′′′22	4	..
	Docosapentaenoic	C′′′′′22	5	..

atoms, number of double bonds and the melting points (m.p.) of the more important fatty acids occurring in the natural fats and oils.

The physical character of a triglyceride depends on that of the constituent fatty acids. For example, the simple triglyceride of stearic acid, tristearin, has a melting point of 71·5°C, while the stearic acid melts at 69·6–70°C. The simple triglyceride of oleic acid, triolein, is liquid at room temperature, as is oleic acid practically also (16°C m.p.). The mixed triglycerides of stearic and oleic acids have melting points which for the distearo-monooleins is 38·5–43°C, depending on the position of the fatty acids in the molecule; for dioleo-monostearin the melting point is 23·5°C. Similarly tripalmitin has a melting point of 65·5°C, dipalmito-monoolein 34·5–36°C and dioleo-monopalmitin 19°C.

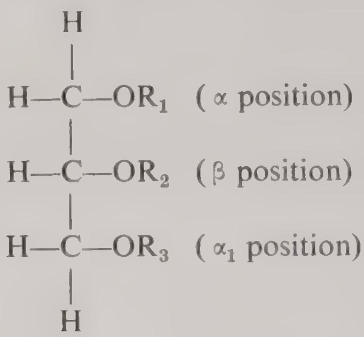
Table VII gives the melting points of a number of the triglycerides most frequently occurring in fats and oils, together with their code nomenclature.

Table VII

Triglyceride	*Melting Point °C*	*Code Nomenclature*
Tristearin	71·5–73	C18 C18 C18
Tripalmitin	65·5	C16 C16 C16
Trimyristin	57	C14 C14 C14
Trilaurin	46·4	C12 C12 C12
Triolein	5	C′18 C′18 C′18
Trilinolein	−13	C″18 C″18 C″18
Trilinolenin	−24	C‴18 C‴18 C‴18
Distearo-palmitin	68	C18 C16 C18
Stearo-dipalmitin	68	C16 C18 C16
Palmito-dimyristin	60	C14 C16 C14
Stearo-dilaurin	51·5	C12 C18 C12
Myristo-dilaurin	50·2	C12 C14 C12
Distearo-olein	41·6	C18 C′18 C18
Stearo-diolein	23·5	C′18 C18 C′18
Dipalmito-olein	35·2	C16 C′18 C16
Palmito-diolein	19	C′18 C16 C′18
Myristo-diolein	13·5	C′18 C14 C′18
Palmito-oleo-linolein	liquid	C16 C′18 C″18
Oleo-linoleo-linolenin	,,	C′18 C″18 C‴18
Trierucin	32·5	C′22 C′22 C′22
Dioleo-monoerucin	liquid	C′18 C′22 C′18

Many of the fatty acids and of the glycerides are polymorphic, i.e., they exist in 2, 3 or 4 different crystalline forms with different melting points and other physical characteristics; they are called α, β and γ forms and as an example may be mentioned palmitic acid, the α-form of which melts at 56°C, the β-form at 65·5°C and the γ-form at 45°C. The lowest melting γ-form is formed by rapid cooling of the liquified acid, the α-form by less rapid cooling, and the β-form which is the stable one is produced by slow cooling. This phenomenon is of considerable practical importance in various industrial processes where fats or fat-mixtures are more or less rapidly cooled and where as the result several of the crystalline modifications may be found. To obtain the desirable results as to texture, consistency and crystal stability special precautions must be observed.

Mixed triglycerides also show differences, depending on the position of the fatty acids in the molecule. In the structural formula the outer acid radicals are stated to be in the α and α_1 position, the inner radical in β position; thus



$$\begin{array}{cl} \text{H} & \\ | & \\ \text{H—C—OR}_1 & (\alpha \text{ position}) \\ | & \\ \text{H—C—OR}_2 & (\beta \text{ position}) \\ | & \\ \text{H—C—OR}_3 & (\alpha_1 \text{ position}) \\ | & \\ \text{H} & \end{array}$$

As an example may be mentioned dipalmito-monostearin which can be either palmito-palmito-stearin with a melting point of 62·5°C or palmito-stearo-palmitin, melting at 68°C.

The natural fats and oils do not consist of a single triglyceride, but of a smaller or larger number of, predominantly mixed, triglycerides, into the composition of which at least 4 or 5 fatty acids, mostly a considerably larger number enter. Although the fatty acid composition of a fat or oil varies slightly with feeding, growth, soil, ripening, etc., analyses of average samples show that butter fat contains 19–20 acids, coconut oil types 11–12, animal fats like lard and tallow 8–10, marine animal oils 9–10, rape oil 10, groundnut oil, cottonseed oil, soyabean oil 7, sesamé oil 5, cocoa butter and hard vegetable butters 4–5, etc.

These acids are distributed in the triglycerides in a manner that in most cases inclines towards the "rule of even distribution", although there are in some fats indications of a random pattern of distribution. Either system leads to a fairly large number of different triglycerides, though where two or three fatty acids are present in preponderant proportions a few triglycerides containing them will also predominate and tend to give the fat or oil its physical and chemical character. It is this tendency of the fatty acid distribution which results in comparatively few triglycerides of melting point above 40–42°C being present in natural fats, at any rate in more than minor proportions, as will be mentioned later under the individual fats. This is a matter of some nutritional significance.

The fatty acid and glyceride compositions of the various fats and oils will be dealt with in later chapters and their effect on the evaluation of the fatty raw materials shown. Descriptions of analytical features and methods of determining them are outside the scope of this book and readers are referred to books on this subject [51] [52] [53] [54] [55].

Reference is frequently made to Melting Point (m.p.) which for individual fatty acids or triglycerides is the point of complete fusion determined in a capilary tube, whereas for oils, fats and their mixtures it is the capillary tube "slip point" which agrees better with the physiological sensation of fats melting on the palate, and it is of better guidance industrially.

As the degree of unsaturation in fats and oils is an important point in judging their stability and suitability for edible products mention will often be made of their "Iodine Value" which measures the degree of unsaturation and, with similar analytical tests, its type. The unsaturation is in some of the fatty acid chains, as described earlier and shown in symbol by the existence of one or more double bonds which indicate a deficiency of hydrogen atoms. This unsaturation can be sated more or less completely by hydrogenation (see page 38) of which important industrial use is made. For analytical purposes it is much simpler to use iodine for absorption at the double bond, hence the unsaturation of a fat is expressed as the amount of iodine absorbed for full saturation by 100 g fat.

For orientation the following examples are given of iodine values (I.V.) of some fatty acids and triglycerides.

TABLE VIII

Compound	*Code Nomenclature*	*Iodine Value*
Saturated fatty acids	—	—
Fully saturated glycerides	—	—
Oleic acid (one double bond)	C′18	89·9
Palmitoleic acid (one double bond)	C′16	99.8
Erucic acid (one double bond)	C′22	75
Linoleic acid (2 double bonds)	C″18	181
Linolenic acid (3 double bonds)	C‴18	273·5
Arachidonic acid (4 double bonds)	C⁗20	333·5
Clupanodonic acids (5–6 double bonds)	C′′′′′20–C 26	328–460
Triolein (3 × 1 double bonds)	C′18 C′18 C′18	86
Trierucin (3 × 1 ,, ,,)	C′22 C′22 C′22	72·3
Trilinolein (3 × 2 ,, ,,)	C″18 C″18 C″18	173·2
Trilinolenin (3 × 3 ,, ,,)	C‴18 C‴18 C‴18	261·6

The iodine value of a mixed triglyceride is in proportion to its content of saturated and unsaturated acids and their chainlength; similarly the iodine values of fats and oils depend on their triglyceride mixture. Where the saturated solid acids form more than *ca.* 45 per cent the iodine value is usually less than 70 and the product is solid at room temperature and generally termed "a fat". Where the iodine value is above 80 unsaturated acids are in majority and the product is liquid and termed "an oil". The borderline is not distinct and there is some overlapping, particularly with partly hydrogenated high-iodine value oils and with some mixtures of high-melting fats and liquid oils. The natural fats vary in iodine value from 8 (coconut oil) to *ca.* 68 (lard), the oils from *ca.* 83 (olive oil) to *ca.* 180 (linseed oil). The unsaturation or reactivity of glycerides towards hydrogen or iodine is also shown towards oxygen, and by some mechanism, on which there is still some difference of opinion, peroxides and more permanent oxidation products, oxyacids, etc. are formed when glycerides are exposed to air, particularly in the presence of strong light, traces of copper and iron, and at temperatures above 50–60°C. The higher the iodine value the more susceptible is the glyceride to oxidation, although it is now generally accepted that some positions of unsaturation, as in linoleic acid and still more in linolenic acid, are particularly reactive in causing the fault in fats and oils known as oxidation rancidity, in fats often called "tallowiness", in oils "oiliness". Knowledge of the unsaturation of fats and oils and, by analogous tests to the iodine value, of the position in the molecule of the unsaturation is therefore important to the manufacturer of edible fats and will frequently be referred to in subsequent chapters.

The rational description of the composition of mixed glycerides involves the use of rather cumbersome terms, such as myristo-lauro-olein, palmito-diolein, stearo-oleo-linolein, oleo-linoleo-linolenin, etc. Where such terms have to be used frequently a simpler code system can be adopted, largely on the lines described and adopted by K. HOFGAARD [56]. If a fatty acid chain in the glyceride molecule is designated by the letter C, followed by the figure showing its number of carbon atoms and marked with apostrophes giving the number of double bonds in the chain, C16 would represent palmitic acid, C′18 oleic acid, C″18 linoleic acid, C‴18 linolenic acid, etc. (see columns marked code nomenclature in Tables VI, VII and VIII). Triglycerides would then have the codes shown in Tables VII and VIII by simply indicating the codes for the fatty acid chains entering the triglyceride composition. Thus stearo-palmito-olein would be C18 C16 C′18, myristo-lauro-olein C14 C12 C′18, palmito-oleo-linolein C16 C′18 C″18, oleo-linoleo-linolenin C′18 C″18 C‴18 and so on.

Where the position of the different fatty acid chains in the glyceride molecule are known (α, β and α_1 positions) this can also be indicated. For example $\alpha\,\alpha_1$-dipalmitin-β-olein would be C16 C′18 C16, or α-palmito-β-oleo-α_1-butyrin would be C16 C′18 C4.

The system can also be used for diglycerides and monoglycerides if instead of the symbol C the symbol OH is shown where there is a hydroxyl group; for example $\alpha\,\alpha_1$ distearin would be C18·OH·C18, $\alpha\,\beta$ distearin C18 C18·OH, β-monolein OH·C′18·OH and so on.

There is by this system no indication of the position of the double bond in the acid chain, but as these positions are now well known in the natural unsaturated acids and in most of the isomers formed by hydrogenation this defect is of no particular importance for the practical use of the code system.

2. GENERAL REMARKS

In the chapter about the history of margarine it was mentioned that Mège Mouriés believed that he had found the mother substance of butterfat in the low-melting fraction of beef tallow, his oleo-margarin. He was aware of the very considerable differences in the chemical composition of the two fats, but ascribed them to incipient deterioration in the butterfat. Whatever his views, he had succeeded in obtaining for his butter substitute the fat which when made by appropriate methods from fresh beef suet and tallow became the favourite fat for margarine made for table use; its texture, consistency and plasticity is very similar to that of butterfat and its flavour blends well with that of ripened milk. It can therefore be used by itself in the production of margarine, and the same is the case with some hydrogenated products of vegetable and marine animal oils, but in most cases it is necessary to mix fats and oils into suitable blends, partly to take advantage of favourable markets, partly to give the margarine the desired characteristics as regards physical, chemical and physiological properties.

To select the proportions of the various fats and oils was for long largely a matter of experience, aided by determination of melting and setting points as well as by practical tests. With the more thorough knowledge of the chemical and physical nature of fats, their glyceride compositions and the effect of these on the properties of margarine, the manufacturer can apply scientific methods in arranging blends to give the different types of margarine required. Except for certain qualities for special uses the character of most margarines is modelled on that of butter. For that purpose a large number of fats and oils is available of which the principal ones are the following:

Animal Fats.—Oleomargarine (oleo), edible beef tallow (premier jus), oleostearine, lard, mutton oleo, and mutton tallow.

Vegetable Fats and Oils.—Coconut oil, palmkernel oil, babassu oil, palm oil; shea butter, groundnut oil (arachis oil, peanut oil), cottonseed oil, soyabean oil, sunflower oil, sesamé oil, maize oil (corn oil), olive oil, rape oil, mustardseed oil.

Hydrogenated Fats.—Those of animal origin are mostly from whale oil, but considerable quantities from herring oil and seal oil are used in some countries. The principal hydrogenated vegetable fats are those from groundnut oil, cottonseed oil, soyabean oil, sunflower oil and rape oil, but most vegetable oils can be suitably hydrogenated.

The manufacturer is guided in his choice of raw materials for the fat-blends not only by cost, but also by the following considerations: Is the fat wholesome and palatable or can it by suitable treatment be made so? Is it nutritionally satisfactory? Are the chemical and physical characteristics right for the finished margarine or can they by suitable modification be made so?

Wholesomeness and palatability are ensured by using well-refined products from sound raw materials; they have either a bland flavour or a pleasant flavour characteristic of the particular fat; the former is preferred to avoid interference with the desired aroma in the margarine.

Most fats and oils are of high nutritive value and practically equivalent (see page 8) except some of high melting point due to their specific chemical composition. On this latter point the following considerations are applied in evaluating the various fats and oils.

3. ANIMAL FATS

Beef Tallow Products.—When prepared by careful rendering from the edible parts of freshly killed carcasses beef tallow, generally termed "Premier jus" or, in U.S.A., "Oleo stock", is one of the original important fatty raw materials for margarine. Since the introduction of the hydrogenation process for oils it has, however, been largely superseded by hydrogenated fats, though it is still of some importance in certain countries with high tallow production, such as Australia, and for special margarines for confectionery and bakery use.

Though the glyceride and fatty acid composition of beef tallow varies a good deal according to type of animal, feeding etc., it may be considered to contain in the glycerides on an average about 48 per cent saturated acids, principally stearic and palmitic acids, but also some myristic acid, and of unsaturated acids about 48 per cent oleic, 3 per cent linoleic and a trace of a higher-molecular unsaturated acid, C''''22?, which through its proneness to oxidation may be responsible for the "fishy" flavour developing in old tallow. The distribution of the fatty acids in glyceride molecules, according to the rules indicated by HILDITCH [48], is such that the fat contains 15–22 per cent fully saturated glycerides, C18 C16 C18, C16 C18 C16, C14 C18 C16, etc., which have a melting point of 60°C or more and make the combined melting point, the capillary tube slip point, of the fat 40–46 C and consequently of rather low digestibility by itself (see page 8). The iodine value of beef tallow is usually 42–48, but as some of the unsaturation is due to linoleic and a trace of higher-unsaturated acid the fat is somewhat prone to deterioration by oxidation.

A more suitable beef fat for a butter-like margarine is the fractionation product oleomargarine or oleo oil, as described in connection with the invention of margarine (page 2). According to the temperature of crystallization and the pressure during fractionation this may vary considerably in melting point and iodine value, but mostly melts between 28° and 34 C with variation in iodine value from 44–55. It contains mostly the mixed saturated-unsaturated, C16 C'18 C16, C'18 C16 C'18, etc., and fully unsaturated, C′18 C′18 C′18, etc., fractions and is therefore less resistant to oxidation than the tallow. It is a very plastic fat and an excellent raw material for margarine.

The harder fraction, which remains after the oleomargarine has been pressed out, is a hard white fat, oleostearine, which contains practically all the fully saturated glycerides, has a melting point of 48°–54°C and iodine value 18–28. It is too hard and of too low digestibility to be suitable for table margarine, but is a good fat for special bakery shortening and pastry margarines.

Mutton Tallow Products.—Mutton tallow is not valued as highly as beef tallow, partly because of its frequently rather strong odour, partly because the higher proportion of stearic acid radicals in the glycerides gives it a melting point 3–4°C higher than that of beef tallow, and this together with the rather high proportion, 26–28 per cent, of fully saturated glycerides makes it somewhat hard and of relatively low digestibility. It is, however, used in some countries both for table and pastry margarines, for the former at times as the fractionation product mutton oleo, while the other fractionation product mutton stearine is used for confectionery fats and shortenings.

Both beef and mutton fats from fresh adipose tissues are used without any refining treatment. If obtained from stored materials they can be refined to edible standard, but are then not of the "extra quality" and are more susceptible to oxidative deterioration leading to tallowy flavour.

Lard.—At one time lard, particularly the quality known as "Neutral Lard", obtained by wet rendering at 50–60°C from kidney and caul fat of hogs, was an important raw material for margarine and highly valued because of its plastic nature and bland flavour. Since the introduction of hydrogenation of oils it has lost much in importance. Lard from mixed deposits, "Prime Steam Lard", is only usable for margarine after refining and even then it is of lower quality.

The melting point varies considerably according to the breed and feeding of the animals, but when used for margarine is generally 32°–40°C, and the iodine values vary from 52–68. On an average lard fatty acids consist of 42 per cent saturated acids (12 per cent stearic, 29 per cent palmitic, 1 per cent myristic) and 58 per cent unsaturated acids (3 per cent C′14 and C′16, 48 per cent oleic, 6 per cent linoleic, 1 per cent higher-molecular unsaturated acids). The small amount of high-molecular unsaturated acids is probably tetra-enoic (C′′′′20), and as the result of this high unsaturation they are very prone to cause oxidative deterioration in the lard. The average glyceride composition of lard is about 5 per cent fully saturated (C16 C16 C16, C18 C16 C18, C16 C18 C16), 32–39 per cent disaturated-mono unsaturated (C16 C′18 C16, C18 C′18 C18, C18 C′18 C16), 49–56 per cent mono-saturated-diunsaturated (C′18 C16 C′18, C′18 C18 C′18) and 3–10 per cent triunsaturated (C′18 C′18 C′18, C′18 C″18 C′18) glycerides. The fatty acids are distributed in this range of glycerides with widely varying melting points, which accounts for the plastic nature and gradual softening of lard on warming. The relatively small proportion of fully saturated high-melting glycerides explains the high digestibility of most types of lard.

4. VEGETABLE FATS

Coconut oil and palmkernel oil are white rather brittle fats with melting points of about 24° and 28°C respectively. They are two of the most important fats for margarine in Europe and many other parts of the world.

Coconut Oil, with iodine value 8–10 contains the radicals of a wide range of saturated acids from C6 to C18, but predominantly lauric acid C12, the saturated acids forming 90–92 per cent, the unsaturated, mostly oleic, 8–10 per cent. Coconut oil has therefore good resistance to oxidative rancidity, but its high proportion of low-molecular acids makes it susceptible, in the presence of moisture, to hydrolysis by lipolytic micro-organisms and moulds with development of unpleasant odour and taste, due largely to the formation of ketonic and aldehydic compounds. The glycerides in coconut oil consist of about 84 per cent trisaturated, 12 per cent monounsaturated-disaturated and 4 per cent diunsaturated-monosaturated compounds, but as the fully saturated glycerides contain mainly lauric and myristic acids of relatively low melting points they are also of low melting point and their digestibility is high. In temperate climates coconut oil is solid except in hot summers, but in the tropical countries of its origin it is liquid, hence the name. The low percentage of fully liquid glycerides explains the brittle nature of the fat in solid form.

Palmkernel Oil, from the kernel of the fruit which from its fruit flesh yields palm oil, is very similar to coconut oil in appearance and glyceride make-up. As the fatty acids consist of about 17 per cent unsaturated, mostly oleic, and 83 per cent saturated, of a wide range like coconut oil and predominantly lauric and myristic, the iodine value is a little higher, 15–18, and the oil is therefore slightly more liable to oxidation than coconut oil, though rather resistant. Like the latter it is prone to hydrolysis by micro-organisms in the presence of moisture.

Coconut oil and palmkernel oil are generally considered so similar as to be interchangeable in fat mixtures. This is only correct as far as their chemical and physical characters are concerned. Most margarine manufacturers consider refined coconut oil to have a "sweeter" flavour and more attractive palate-appeal.

Babassu Oil is very similar to coconut and palmkernel oils and is derived from a South American palm. Compared with the two other oils it is only available in minor quantites at present. The fatty acids consist of about 82 per cent saturated, principally lauric and myristic, and about 18 per cent unsaturated, mostly oleic. The glycerides are made up from 63 per cent trisaturated, 30 per cent monounsaturated-disaturated and 7 per cent diunsaturated-monosaturated. The melting point is about 26°C and the iodine value 15.

Palm Oil.—This is the fat from the fruit flesh of the palm *Elaeis Guineensis* and quite different from the fat of the kernel. It is only during the last 25 years that palm oil has become an important raw material for margarine. As long as the oil was obtained by primitive native methods from wild palms it deteriorated rapidly by enzymic hydrolysis and oxidation, and when reaching the refineries could not be refined economically to edible standard. With the development of palm plantations in Congo, Indonesia, Malaya and some other tropical regions and with the introduction locally of modern methods of fruit collection, oil milling and extraction oil with low free fatty acid content, 5 per cent or less, reached the refineries and could be converted into high-grade edible fat.

The crude oil is of dark yellow or orange colour due to its content of carotene, which is of biological importance as a precursor of vitamin A and is present in varying amounts, in some types of palm oil up to 1000 micrograms per gram. In refining the crude oil to a practically tasteless white or pale yellow fat the carotene is lost. For some purposes palm oil is given a mild, low-temperature refining treatment without bleaching in order to retain the carotene. The oil is then used for giving colourless fat mixtures a butter-yellow colour and imparting a moderate vitamin A activity. An addition of *ca.* 0·5 per cent or less will give a yellow colour to the mixture and a vitamin A potency of about 6–10 international units per gram. More than 1 per cent cannot be added of this deep coloured palm oil without imparting a flavour like violets which is characteristic of carotene. Fully refined and bleached palm oil can be used in large proportions for margarine, shortenings and biscuit fats.

The fatty acid—and consequently the glyceride—composition of palm oil varies a good deal according to country of origin and variety of tree. The average iodine value is 55 (variations 53–60), the melting point 33–39°C. Of the fatty acids about 48 per cent are saturated, mostly (41 per cent) palmitic, and 52 per cent unsaturated, including less than 10 per cent linoleic. A well refined oil is therefore fairly resistant to oxidation. About 7 per cent of the glycerides are trisaturated, C16 C16 C16 and C16 C18 C16 and 45 per cent disaturated, C16 C′18 C16 and C16 C′18 C18; about 44 per cent are diunsaturated, C′18 C16 C′18, and 4 per cent triunsaturated. As the tri- and disaturated glycerides have melting points above 30°C and the di- and tri-unsaturated glycerides melt below 20°C, the fat shows a tendency with the relatively simple glyceride composition to soften considerably at 25°C and upwards and cause graining-out by the higher melting glycerides forming firm crystals in the matrix of soft and liquid glycerides; the fat is therefore in the tropics usually in semi-fluid condition. This glyceride composition may cause difficulties with the consistency of margarine, unless it is compensated for in the full fat-blend, but it also helps to obtain a very plastic product with correct processing.

Shea Butter.—This is the name given to the refined edible fat of sheanut oil, in France termed Karité oil, from the African palm *Bassia Parkii*. It is in the refined form a greyish white to white, tough, slightly plastic fat, melting at 38–40 C and with iodine value about 60. It has about 46 per cent saturated fatty acids, mostly stearic, and 54 per cent unsaturated, oleic acid and about 4 per cent linoleic. The glyceride composition is very simple with about 5 per cent trisaturated, 34 per cent disaturated, 56 per cent diunsaturated and 5 per cent triunsaturated glycerides. The fat therefore retains its tough plasticity over a rather wide range of temperatures. It is characterized by a high content of unsaponifiable matter, 4–9 per cent, and this as well as its polymorphic behaviour when solidifying after melting makes it rather unsuitable for table margarines, except in small proportions, but it is a very suitable vegetable fat for confectionery margarine, particularly for "flaky" pastry. The quantities available at present are relatively small, but there are potentially very large sources in Africa.

5. VEGETABLE OILS

As far as physical characteristics are concerned the vegetable oils are practically equivalent and interchangeable in the margarine blends, but there are considerable differences in the chemical characteristics which influence the margarine manufacturer's evaluation of them. Modern refining technique makes it possible to produce from them refined products of practically equal flavour quality; the assessment of value is therefore based on price and quality stability. On the latter point it is essentially the resistance to oxidative deterioration that has to be considered. By and large this depends on the degree of unsaturation of the oil, which is usually measured by the iodine value, but it is also important to ascertain to what extent the unsaturation is due to monoethenoid acids (with one double bond, oleic acid and homologues), to diethenoid acids (two double bonds, linoleic acid), triethenoid acids (three double bond, linolenic acid) and acids of higher unsaturation (poly-ethenoid acids, arachidonic acid, "clupanodonic" acids, etc.). For example, linolenic acid is relatively more reactive towards oxidation than linoleic acid, and this again more reactive than oleic acid. Thus, sunflower oil and soyabean oil have practically the same iodine value, but soyabean oil is more susceptible to oxidation, as it contains some linolenic acid radicals whereas sunflower oil contains none. It is therefore customary now to study unsaturation of oils by additional analytical methods to iodine value determination, for example the thiocyanogen value and spectrographic methods.

While vegetable oils were earlier all obtained by hydraulic pressing or by expelling of the oil-bearing material, solvent extraction, or expelling followed by solvent extraction, has during the last two decades become equally or more important owing to the advantage of the higher yield of oil, the most valuable fraction of the seed. However, with the high-grade solvents now available and with modern refining methods, oil from either process can be made equally suitable for the manufacture of margarine.

Olive Oil.—This is the most expensive of edible oils and therefore little used in margarine, except where special national economy or statutory regulations make it compulsory. As to quality and chemical composition it offers practically no advantage over groundnut oil. The best grades, virgin oils, are usable without refining as salad or table oils, but the flavour is as a rule too characteristic for use in margarine, and the free fatty acid content, 0·5–2 per cent, is too high. It would therefore require mild refining for that purpose, and lower-grade oils would need a more thorough refining treatment.

The iodine value is about 85. The fatty acids consist of 10–12 per cent saturated, largely palmitic, and 88–90 per cent unsaturated, oleic with about 7 per cent linoleic. The fact that unsaturation is principally due to oleic acid makes the oil relatively resistant to oxidation. The fatty acids are distributed in the glycerides to form less than 2 per cent fully saturated, about 43–45 per cent monosaturated-diunsaturated and about 55 per cent triunsaturated glycerides. The very low content of fully saturated glycerides makes the "clouding" or turbidity point of olive oil on cooling very low, about −6°C, which is important for its use as salad oil.

Olive oil has been used both in liquid form and as a hydrogenated fat for margarine in Italy and other countries with extensive olive oil production, but very rarely outside these places.

Groundnut Oil.—The chemical composition of this oil makes it the most suitable of those generally used as liquid oil in the composition of margarine fat-blends. When derived from sound nuts it is easily refined to give a pale yellow oil of pleasant mild or bland flavour. The relatively low iodine value of 85–95 places it among the so-called non-drying oils which show good resistance to oxidation. Its fatty acids consist of 17–20 per cent saturated and 80–83 per cent unsaturated. The former are mostly palmitic, but significant amounts of stearic, arachidic, lignoceric and behenic are also present. In West African oils the unsaturated acids are about 60 per cent oleic and 20 per cent. linoleic; the iodine values are therefore of the lower range, and these oils are preferred for margarine. In oils from other places the proportions of oleic and linoleic acids approach equality and the iodine values are higher; Chinese and Argentine oils may approach 100 I.V. and these oils are less resistant to oxidation. Apparently, climate and variety of the plant are responsible for the differences in fatty acid composition.

The acids are distributed in the glyceride molecules such that there is generally less than 10 per cent disaturated glycerides present. The percentage of diunsaturated and triunsaturated glycerides may be about equal, but as most of the former melt at 20°C or below and the latter are liquid the presence of the small percentage of fairly high-molecular saturated fatty acids, C18, C20, C22 and C24, does not affect the digestibility of the oil which of the order of 97–99 per cent; their presence in the disaturated glycerides is, however, probably responsible for the turbidity and jelly-like congealing of this oil at cool room temperatures, 8–12°C, which makes it less suitable for salad oil in colder climates [57] [58].

Cottonseed Oil.—This oil is produced predominantly in U.S.A., but very large quantities are also produced in India and Pakistan, China, Brazil, Egypt, Russia, and considerable quantities in Africa and many other countries. The crude oil has a strong flavour and a dark reddish-brown colour owing to the presence of gums and a dark pigment, gossypol. It requires a rather drastic refining treatment, but the very efficient modern methods yield a pale yellow mild and pleasant tasting oil which is very valuable for use in margarine and in shortenings and as a table oil. The American oil is usually considered the best grade, followed by the Egyptian, but much depends on climatic conditions during growth of the seed, on storage and on milling conditions; the better the seed, the better the crude oil and the easier to refine.

The iodine value of cottonseed oil ranges from 104 to 112, varying with its origin. The fatty acids consist of about 25 per cent saturated, nearly all palmitic, and 75 per cent unsaturated, of which about 45 per cent the diethenoid linoleic acid, the remainder monoethenoid, practically all oleic. The high percentage of linoleic acid makes the oil more susceptible to oxidation than groundnut oil, but when used with reasonable precautions during manufacture, and in most margarine compositions, it is valued as a high-grade oil. In some countries the unsaturation is reduced by more or less extensive hydrogenation which permits the use of very high proportions in margarine blends. While from the point of view of quality stability the high linoleic acid is a disadvantage, it is claimed to be a nutritional advantage as linoleic acid is one of the "essential" fatty acids for nutrition and even a small proportion of cottonseed oil in the fat-blend will give an adequate "essential" fatty acid content. It is, however, yet undecided whether these acids are essential for human nutrition, though they seem to be so for animals (see also page 11).

The fatty acids are distributed in the glycerides in such a manner that there are present 12–20 per cent monounsaturated, C16 C′18 C16 and C16 C″18 C16, 50–60 per cent diunsaturated, C′18 C16 C′18 and C″18 C16 C′18, and 26–30 per cent triunsaturated glycerides, C″18 C′18 C″18. They are all liquid or melt well below body temperature. As there is only a negligible trace of trisaturated glycerides present, about 0·1 per cent, cottonseed oil is of high digestibility, 97–99 per cent.

Soyabean Oil.—The introduction of this oil for use in edible fat products in the Western world dates back to the years just before the First World-War. While originally the beans and the oil came from China and Manchuria the cultivation of the plant and the production of the oil has spread to many countries, the most spectacular development being in U.S.A. where the soyabean production and industry during the Second World-War has grown to such an extent that the tonnage of oil exceeds that of cottonseed oil and is of the order of a million tons or more, and most of this is used for edible purposes.

Crude soyabean oil, which is now nearly always obtained by solvent extraction of the bean, contains a higher proportion, up to 2–2½ per cent, of phosphatides, "soya lecithin", than other oils and fats, and this is frequently separated and treated to form a valuable by-product, vegetable lecithin, which is used as a surface-active emulsifier, for example in the manufacture of margarine. It is an advantage to remove the bulk of the phosphatides by hydration, centrifugation or de-gumming before refining in order to minimize losses in the alkali neutralization process or to avoid damaging the oil in the steam distillation de-acidification process. With modern methods of treatment soyabean oil is refined to a good edible oil of mild flavour, practically free from the characteristic beany flavour of the crude oil. There is, however, a tendency for some of the beany flavour to "revert" some time after refining. Much research has been done in this subject in U.S.A. and published during recent years [59]. The difficulty arises more in the manufacture of shortenings than in margarine compositions where some of the ingredients seem to counteract the reversion.

The iodine value of soyabean oil lies usually between 130 and 135. Of the fatty acids 12–15 per cent are saturated, mostly palmitic, 25–30 per cent oleic, 50–55 per cent linoleic and 5–9 per cent the triethenoid linolenic acid. It is the latter that is principally responsible for the flavour reversion of refined oil, referred to above, and the high unsaturation of linolenic acid makes soyabean oil markedly susceptible to oxidation. It is classified as semi-drying oil.

The fatty acids are distributed in the glyceride molecules in accordance with the rule of even distribution; consequently the glycerides are either liquid or of low melting point. They have been calculated to consist of 0–5 per cent monounsaturated, 30–35 per cent diunsaturated and 40–60 per cent triunsaturated [60] [61]. The digestibility of the oil is of high order, 97–99 per cent. As both linoleic and linolenic acids are considered "essential" for nutrition soyabean oil is a good source for that purpose. The unsaturation and thus the susceptibility to oxidation can be reduced considerably by hydrogenation; hence the hydrogenated form is often preferred and, at any rate in U.S.A. and Canada, much larger quantities are used in margarine and shortening in that form than as liquid oil.

Sunflower Oil.—This is obtained from a variety of seeds, black, "white" and striped, originally predominantly in Russia, Hungary, Black Sea countries and Argentine, but now in many parts of the world. The crude oil from undecorticated or partly decorticated seed is often turbid from a very small fraction of wax from the seed coat, but it is easily refined to give an edible oil of pale yellow colour and very good flavour, and very suitable for use in margarine and as a table oil. In aërated shortenings the unsaturation of the oil—it is classified as semi-drying—makes it rather susceptible to oxidation and manufacturers generally prefer it more or less hydrogenated. In margarine it is used either liquid or hydrogenated. In Russia it is the principal fatty raw material for that purpose.

The iodine value varies between 127 and 137, average 133, but as shown by Hilditch *et al.* recently the iodine value and the proportions of the unsaturated acids depend on climatic conditions and particularly on the rate of ripening of the seed [62] and local production may fall well outside the usual limits. Oil from selected localities and particularly favourable climate may approach groundnut oil in iodine value and content of unsaturated acids which would make this variety of sunflower oil still more valuable and equivalent to groundnut oil and better than the latter as table oil. The generally recorded fatty acid composition is 10–14 per cent saturated acids, nearly all palmitic and stearic, 25–35 per cent oleic and 55–65 per cent linoleic. No linolenic acid has been found and this oil is therefore superior to soyabean oil, otherwise of similar composition, in resistance to oxidation and therefore in general edible utility.

With the acids following the rule of even distribution in the glycerides these approximately consist of 25 per cent monosaturated-diunsaturated, 45 per cent triolein and 60 per cent. olein-dilinolein, C″18 C′18 C″18. The varieties of sunflower oil with iodine values of 100 or less have about 30 per cent monosaturated-diunsaturated glycerides, 25 per cent of triolein, C′18 C′18 C′18, and 45 per cent olein-linoleins, C′18 C″18 C′18 and C″18 C′18 C″18. The digestibility of sunflower oil is of the usual high order of 97–99 per cent.

Sesamé Oil.—The crude oil is of strong yellow colour and is derived from seeds grown mostly in China and India, and in fair quantities in Turkey. It refines to a pale yellow oil of very pleasant flavour. It contains in its crude form a phenolic substance sesamol in a glucoside sesamoline, which has pronounced anti-oxidant properties and together with small quantities of tocopherol makes this oil particularly resistant to oxidative rancidity. Furthermore, sesamol gives in the Baudouin test with furfuraldehyde a strong red colour, for which reason a proportion, 2–10 per cent, of sesamé oil is a compulsory component as indicator substance of margarine blends in some countries. It should, however, be realized that sesamol is destroyed or distilled off in high-temperature deodorization; sesamé oil intended for indicator should therefore not be deodorized above 160° C. At that temperature it may be difficult to eliminate all "crude" flavour, unless the oil is from very good seed; as the deodorization temperature increases the reactivity progressively lessens and usually disappears at 190–200° C.

The iodine value is usually 109–114. The fatty acids consist of 13–17 per cent saturated, nearly all palmitic and stearic, 35–48 per cent oleic and 38–48 per cent linoleic. The acids are distributed in the usual way in the glycerides to give about 5 per cent monounsaturated, 41 per cent diunsaturated and 54 per cent triunsaturated glycerides. Of the latter about 40 per cent are oleo-dilinoleins, C″18 C′18 C″18; a trace of trilinolein may be present. The distribution of the saturated acids in the glycerides gives sesamé oil the usual high digestibility of liquid oils and also a "cloud" point below 0°C; hence it is a popular salad oil.

Corn Oil or Maize Oil.—This is obtained from the germ of the maize seed which arises as a by-product from the manufacture of corn starch or glucose. The crude oil is of deep amber colour and has a characteristic sweet spice flavour. When refined it gives a strong yellow oil of pleasant, nearly bland flavour. Corn oil is produced principally in U.S.A., but also in fair quantities in various maize producing countries, Hungary, Russia, Argentine, etc. It is mostly used for cooking and salad oils, but in several localities for margarine, if available.

In fatty acid composition corn oil is very similar to sesamé oil. The iodine value is on an average a little higher, 115–120, owing to a slightly higher proportion of linoleic acid, but it makes very little difference to the glyceride composition. Although much favoured as a salad oil it has a tendency, even in the refined oil, to develop a slight cloudiness in cool condition owing to the presence of a trace of wax from the seed coat; its removal requires "winterization". Corn oil also contains antioxidants of the tocopherol type and therefore keeps well in spite of its content of olein-dilinoleins.

Rapeseed and Mustardseed Oils.—These oils are very similar and often found in mixture owing to mixing of the seeds in the trade. Rapeseed oil is derived from several varieties of Brassica Campestris (rape, colza, ravison seeds), yellow and black mustard seed oils from Brassica Alba and Brassica Nigra. The principal regions of growth of the seeds are China and India, but cultivation in lesser quantities is rather widespread in regions round the Black Sea, Germany and Poland. During and since the recent war cultivation of these seeds has been developed to locally significant proportions in Scandinavia and Finland, where the oils have become important indigenous raw materials for margarine and other edible fats, both as liquid and hydrogenated oil.

The crude oils are of rather deep yellow to brown colour and have a pungent flavour of mustard oil. They have a fairly high phosphatide content, 0·4–0·5 per cent, the recovery of which has occasionally been practiced in Europe, but the yield and quality is much below that from soyabean oil. Some organic sulphur compounds are sometimes present as the result of enzymic decomposition of a glucoside, sinigrin or sinalbin containing an isothiocyanate compound, in the seed when stored wet, and these may cause some difficulties when the oils are used for hydrogenation, but suitable refining methods eliminate the impurities, and good edible products are obtainable both as refined oils and hydrogenated fats.

The iodine values of these oils vary from 95–110; and the proportions of saturated and unsaturated acids are similar to those of other non-drying oils, namely about 5–7 per cent saturated, of which the high-molecular behenic C22 and lignoceric C24 often form the larger proportions, 74–80 per cent monoethenoid unsaturated, of which oleic acid forms 15–20 per cent and the higher-molecular erucic acid, C′22, 45–52 per cent, 15–20 per cent diethenoid linoleic acid, C″18, and 2–7 per cent triethenoid linolenic acid, C‴18. The characteristic feature of these oils as regards fatty acid composition is therefore the high content of erucic acid, which being a

C′22 acid causes the saponification value of these oils to be relatively low, 170–180, compared with the usual 190–195 for most vegetable oils.

The glyceride composition of this group is approximately 20 per cent monosaturated-monoerucin-monoolein or linolein, C18–24 C′22 C′18 and C18–24 C′22 C″18, 30 per cent monoerucin-diolein, C′18 C′22 C′18, and 50 per cent monoolein-dierucin, C′22 C′18 C′22. The very small amount of linolenic acid that has been reported in some analyses substitutes probably some of the linoleic acid in the monosaturated glycerides. Most of the glycerides are of monoethenoid unsaturation and therefore show good resistance against oxidation; they are all liquid or, in the case of the monosaturated glycerides, melting below 20°C; the oils have therefore low cloud point and are in many countries used in salad oil mixtures, for which purpose their rather viscous nature, compared with most other vegetable oils, is an advantage.

The intestinal absorption or digestibility of rapeseed and mustardseed oils have from time to time been reported as being rather low in comparison with other edible oils. Whether this is due to the high-molecular radicals of behenic, lignoceric and erucic acids and their effect on calcium and magnesium compounds in the diet or to insufficient refining is not quite clear; it appears that experiments on animals have shown a lower coefficient of digestibility, whereas tests on humans have shown digestibility of the usual high order for vegetable oil, 96–98 per cent [63]. Similar doubts have been expressed on the hydrogenated oil where erucin is changed into the high-melting behenin.

Other Vegetable Oils.—The oils mentioned so far are those most widely used for edible oils, fats and margarine, but there are several others which have been used from time to time when prices have been particularly favourable or other oils have been difficult to obtain; frequently they have only been of local importance. Such oils are, for example, kapok oil, mainly from Indonesia and very similar to cottonseed oil; teaseed oil, from China and similar to olive oil; safflower oil, from East Asia and between sunflower and soyabean oil in type; poppyseed oil, Russia, Eastern Europe, the Orient and similar to sunflower oil; pumpkin oil, Hungary, Balkans; tobaccoseed oil, Balkans, and others. If oils contain no physiologically harmful ingredient, as do for example castor oil and hydnocarpus oil, and can be refined to a flavourless product, they can be considered for edible purposes. They should however be of the non-drying or semi-drying type, i.e., the iodine value should not exceed 135–140; they should preferably in their fatty acid chains contain only of the unsaturated acids mono- and diethenoid acids, or at any rate not more than 2–3 per cent triethenoid acids. Admittedly linseed oil, a pronounced drying oil with iodine value about 180 and about 25 per cent triethenoid linolenic acid, has been used here and there for edible purposes after special refining, but the "varnishy" flavour reverts after a few hours and it imparts an unpleasant flavour to margarine. It can be hydrogenated and thus become more resistant to oxidation, but before it becomes sufficiently stable for practical purposes it has to be hydrogenated so far that it is too hard for margarine and its digestibility is greatly reduced.

6. ANIMAL OILS

Those of practical value for edible purposes are whale, seal and fish oils. The former are mostly obtained from the body fats, the blubber, of several species of whales, such as the blue whale, fin whale, humpback and some others, and from seals; the latter by extraction of fat from the whole fish, such as herrings, sardines, pilchards and menhaden.

In their natural form these oils are quite unsuitable for edible use as their fatty acids contain a considerable proportion of highly unsaturated acids of high molecular values, $C^{IV-VI}20$, $C^{IV-VI}22$, $C^{V-VI}24$. They deteriorate and oxidise rapidly after extraction and can only be considered for edible use after modification, principally by hydrogenation.

Whale Oils have iodine values of 105–120, i.e., similar to cottonseed oil, and the proportions of saturated acids, about 25 per cent, and unsaturated acids, about 75 per cent, are also similar, but the former, though palmitic acid forms the major part, contain a fair proportion of myristic acid, and the latter contain a wide range of acids from C14 to C24 varying in unsaturation from monoethenoid to pentaethenoid or more, i.e., from acids with one double bond to those with five or six, the latter often referred to as "Clupanodonic" acids. These highly unsaturated acids with 4, 5 and 6 double bonds form as much as 20 per cent of the total acids and explain the great susceptibility of whale oil to oxidative rancidity and "fishiness". The large number of fatty acids are distributed over a wide range of mixed glycerides, 16 per cent disaturated, 2·5 per cent trisaturated, about 50 per cent monosaturated and 30 per cent triunsaturated [64] which on part-hydrogenation impart valuable properties as regards plasticity to the resulting fat; whale oil itself, though improved by refining and deodorization, soon reverts in flavour and therefore cannot be considered for margarine or edible fat. When hydrogenated and refined it is an important raw material for margarine, particularly in Europe.

Seal Oil is very similar to whale oil in composition and can be used in hydrogenated form for edible purposes, but it is usually not available in large quantities except locally, for example in Norway, where it is sometimes mixed and processed with whale oil.

Fish Oils.—These oils are inferior to whale and seal oils, partly because they are obtained by rendering or extraction of the whole fish and not from separated fat-deposits, partly because they are more unsaturated and therefore more liable to deterioration. They contain approximately the same range of fatty acid radicals and glycerides as whale oil, but in varying degrees more of the highly unsaturated acids. Herring oil has an average iodine value of 135–140, menhaden oil 160–175, sardine oil 170–190, pilchard oil 180–195. The increase in "clupanodonic" acids is approximately parallel to the increase in iodine value. The liquid natural oils, even after intensive refining, are quite unsuitable for use in margarine, but after hydrogenation and refining moderate proportions can be used; more thorough hydrogenation is, however, required to eliminate excessive unsaturation than is necessary with whale and seal oils; the hydrogenated fish oils therefore become harder and of rather high melting point before there is a sufficient lowering of the iodine value, and the digestibility is consequently reduced.

7. MODIFIED FATS AND OILS

Fatty raw materials which, because of their physical or chemical features, are deficient in some respect for the purpose for which they are required may often be modified to make them more suitable. The principal processes for that purpose which have proved of practical value are Fractionation, Hydrogenation, Interesterification and Transesterification, and Polymerization. Modified fats from more or less extensive synthesis have also been used in special circumstances.

Fractionation.—Part of the original process for the manufacture of margarine, as described in the inventor's patents, was a fractionation of beef tallow to obtain a better and lower melting fat, oleomargarine (see page 2). According to the fractionation or crystallization temperature and separation pressure employed the trisaturated and part of the disaturated glycerides are mostly found in the *ca.* 40 per cent of the high-melting fraction, oleostearine, which is particularly valuable as part of the fat-blend for pastry margarine and for shortenings, whereas the lower-melting and the liquid glycerides form the bulk of the *ca.* 60 per cent fraction of oleomargarine or oleo-oil, a very valuable fat for table and cake margarine.

A similar fractionation process by crystallization followed by separation under hydraulic pressure or by pressure filtration is applied to coconut oil and palmkernel oil, where the higher-melting fraction, coconut stearine, iodine value 4–6, melting point 27–29°C, and palmkernel stearine, iodine value 10–12, melting point 32–34°C, are highly valued as confectionery fats and substitutes for cocoa butter because of their brittle nature and "snap" fracture. The lower melting fractions, coconut oleine, iodine value 10–12, melting point 20–21°C, and palmkernel oleine, iodine value 20–22, melting point 22–24°C, are after suitable refining used for margarine fat-blends or are used after complete hydrogenation as brittle confectionery fats of higher melting point than the stearines. The fractionation process often causes a slight deterioration of the more unsaturated fractions, the oleines, and they have to be carefully refined and are usually not as highly valued as the unfractionated products.

Where for ritual or dietetic reasons a vegetable tough but still plastic fat of rather high melting point is required for confectionery and pastry margarines, fractionation by crystallization of palm oil will yield a suitable product in the form of the higher melting fraction. When kept at 24–28°C for some days the trisaturated and a proportion of the disaturated glycerides from palm oil, according to the temperature of storage, form grains in the semi-solid matrix and can be separated by pressing or pressure filtration at the storage temperature. The harder fraction with a melting point of 43–46°C gives after refining a tough plastic fat of excellent keeping and baking quality, rather similar in physical properties to beef tallow. The softer fraction can after refining be used as a softish fat for margarine and shortening; it is often hydrogenated; its keeping quality is not so good as the unfractionated palm oil owing to the higher proportion of unsaturated glycerides.

In recent years processes have been introduced for effecting the fractionation in organic solvents. The glycerides in a fat have different solubilities, according to their chemical composition, in various organic solvents, the solubility varying with the temperature. This fractionation process was originally developed for mixtures of fatty acids, using methanol as solvent. The more complicated glyceride mixtures require other solvents; for moist crude oils semi-polar solvents such as isopropylacetate, methyl ethyl ketone, etc.; for dry neutralized fat acetone or benzene can be used. The fat is dissolved in 2–3 parts of solvent, cooled to a suitable temperature at the right rate of cooling and stirring to develop a suitable crystal formation and then filtered. Crystallization in a solvent is much more rapid as the crystals are right away developed in the stable β-form, whereas owing to the polymorphism of many glycerides slow crystallization in the older way takes place via the unstable γ- and α-forms and often takes several days to reach the stable β-form. Removal of the solvent by evaporation after filtration yields fractions, the types and composition of which depend on fat-solvent ratio and crystallization temperature. Refining and deodorizing gives edible products, generally more sharply fractionated than by pressing or filtration in the older manner.

While the crystallization-fractionation processes are applied to solid and semi-solid fats with a fair proportion of solid glycerides they cannot be applied at practical temperatures to liquid oils, and the fractionation of the latter is rarely of importance for edible purposes. The liquid-liquid extraction fractionation process which has been introduced in U.S.A. principally for obtaining a more drying fraction from a semi-drying oil, mainly soyabean oil, yields as secondary product a liquid fraction of less unsaturation than the original oil and therefore more suitable for edible purposes than the latter and it finds an outlet for that purpose. The only process so far used industrially is that developed by the *Pittsburgh Plate Glass Co.* [65] [66], in which furfural, sometimes mixed with naphtha, is the solvent. It has under the working conditions of the process greater affinity for the more unsaturated fraction, forming the so-called "extract" with good drying properties, whereas the less unsaturated fraction, the "raffinate", after removal of the remnant of solvent and refining gives an improved edible oil. The process is carried out in continuous counter-current in special extraction columns, and from a soyabean oil of original iodine value of 135 about 70 per cent of an improved edible oil with iodine value about 115 can be obtained. Another liquid-liquid fractionation process has been developed by the *Kellog Co.*, U.S.A. This employs liquid propane as a solvent, but this is less selective for glycerides and the process is so far only used for the removal from oils and fats of non-glyceride impurities or valuable by-products such as vitamins [67].

Hydrogenation.—It has already been mentioned (page 5) that the introduction of the hydrogenation process for converting liquid oils into more or less hard fats was of utmost importance to the edible fat and margarine industries. The gradual elimination of double bonds in the unsaturated glycerides enabled the manufacturer to obtain from many vegetable oils a very wide range of solid fats varying in firmness from soft and greasy to hard and brittle, and in the case of marine animal and fish oils the saturation or partial saturation of the highly unsaturated compounds with 3–6 double bonds made these for edible purposes hitherto useless materials suitable as edible fats. For information about the hydrogenation process special books should be consulted [68] [69] [70] [71] [72]; only some special points of importance to manufacturers of margarine and shortenings will be mentioned here.

The hydrogenation or hardening process consists in bringing the oil and hydrogen in intimate contact in the presence of a suitable catalyst, in practice nearly always finely divided nickel. To exercise adequate control over the process the oil destined for edible purposes is usually neutralized to avoid formation of nickel soap which through its solubility in oil causes discoloration and leaves traces of nickel in the hardened fat. Furthermore, the hydrogen must be of a high degree of purity, about 99·9 per cent, as impurities may poison or reduce the activity of the catalyst. This, the proportion of which is mostly under 1 per cent, usually 0·1–0·2 per cent, must be prepared under rigid control and, like the hydrogen, be free from impurities which may interfere with the course and activity of the process, both of which affect the type of product aimed at. The finely divided catalyst may be used on a carrier, such as kieselguhr or other silica-alumina compounds, or as an organic salt, for example the formate, reduced in oil; rigid nickel catalysts are also sometimes used and finely powdered nickel-aluminium alloys.

The purity of oils and hydrogen, the type, purity and proportion of catalyst, the temperature and pressure during the reaction as well as the degree of contact and agitation determine the rate, course and selectivity of the reaction. The rate is the speed at which hydrogen is absorbed as measured by the reduction in iodine value or in refractive index; the "course" is the way isomerization takes place in unsaturated compounds while saturation gradually proceeds; the selectivity is the extent to which hydrogen attaches itself to the most unsaturated acid radicals before those less unsaturated are reduced, for example linolenic acid radicals reduced to linoleic before the latter are changed to oleic and so on. Absolute selectivity is never achieved, nor is complete isomerization before hydrogen absorption or complete suppression of isomerization, but the processor can influence these features by the mentioned means. This is of great importance to manufacturers of margarine and shortenings, as apart from producing from a certain oil a number of fats of different melting points as the result of different degrees of saturation, he can from the same oil obtain fats with the same degree of saturation, but of quite different physical characters. For example, a groundnut oil reduced in iodine value by hydrogenation from 90 to 72 by selective and iso-suppressive procedure yields a soft semi-fluid fat, unsuitable for most margarines in major proportions, whereas the same oil reduced to the same iodine value by iso-promoting procedure gives a firm plastic fat of about 33°C melting point and usable in margarine to the extent of 60–80 per cent. For oils containing oleic, linoleic, linolenic and more unsaturated acid radicals the kinetics of the reaction are more complicated, whether selective or non-selective conditions are established, but the means of control, as far as it is possible, are those mentioned above [73] [74] [75].

While it is clear from what has been stated that a practically infinite variety of fats can be produced by hydrogenation, a brief summary is given below of the principal types used in the manufacture of margarine.

While *hydrogenated whale and fish oils* have so far found little or no application for margarine in America they are important raw materials in other parts of the world, Europe, Africa and the Far East. It is, of course, essential that they, as well as all hydrogenated fats for edible use, are given a full refining treatment after hydrogenation in order to remove by neutralization any free fatty acids that may have been formed by hydrolysis under the pressure and temperature conditions in the reaction vessels; an adsorption clarification and bleaching should follow to remove remnants of soap, nickel catalyst and colouring compounds, and finally adequate steam deodorization in high vacuum to remove undesirable flavours, including the characteristic "hardening" flavour developed during hydrogenation. The nature of this is not yet fully known, but seems to be proportional to the contents in the original oil of fatty acid radicals more unsaturated than oleic.

Whale oil with its very large range of mixed glycerides gives for that reason on hydrogenation plastic facts over a wide range of iodine value reductions from the original 115–120 when the course of hydrogenation permits the formation of 20–30 per cent of "iso-oleic" acids. Fats of melting points 30°C to 50°C, corresponding to iodine values of 80–20, are used, but the principal products are of 34°C m.p., I.V. 72, 36°C m.p., I.V. 66, 40–42°C m.p., I.V. 55–50, 45–46°C m.p., I.V. 40, and 50–52°C m.p., I.V. 22–20. The latter is only used in shortenings and confectionery margarines, the 45–46° m.p. material similarly and in moderate amounts in household margarine. Many manufacturers decline to use hydrogenated whale oil of iodine values above 60, as there is evidence that even under fairly selective hydrogenation conditions some of the highly unsaturated compounds are still present and tend to cause an early reversion of "hardening" flavour and some oxidation. On the other hand margarine manufacturers do not favour for household margarines fats with more than a small percentage of trisaturated glycerides with C16 and higher fatty acids, as they have a tendency to make the margarine "heavy on the palate" and reduce the digestibility; on the whole, therefore, hydrogenated whale oil of 40/42°C m.p. is the most widely used. For shortenings, however, a fair proportion of trisaturated glycerides often help to extend the plastic range in mixture with softer fats and to increase "creaming power". Fully hydrogenated whale oil has a melting point of 54–55°C.

Seal Oil is so similar to whale oil that what has been mentioned about the latter also applies to the former.

Fish Oils, important raw materials in the Far East, have higher iodine values than whale oil and therefore when hydrogenated to equal iodine value with whale oil are of firmer consistency. To guard against flavour reversion and oxidation they should be hydrogenated below an iodine value of 50–52 and are then too firm and high-melting for incorporation in blends for good household margarine at more than 10–15 per cent.

Hydrogenated Groundnut Oil is of the vegetable oils the most widely used and highly valued. The unsaturation in the liquid oil is mostly due to oleic acid; of more unsaturated acids there is only linoleic which in some varieties may be as high as 35–40 per cent. Under suitable selective conditions this oil can be hydrogenated with practically complete elimination of linoleic acid before there is a considerable increase in saturated acids, the hydrogenation changing linoleic acid to oleic or "iso-oleic"; at an iodine value of 70–72 such a product is semi-fluid. Where for special reasons it is important to reduce the linoleic content of groundnut oil to the minimum and still preserve the liquid character of the oil, highly selective hydrogenation conditions makes it possible to get an oil of iodine value 75–78 with only 0–2 per cent linoleic acid. For margarine a hydrogenated groundnut oil of 32–33°C m.p. and 70–72 I.V. is much used, but to give it the necessary solid consistency for use in very high proportions, 70–80 per cent or more, the hydrogenation conditions should favour formation of a high percentage of "iso-oleic" acids without appreciable increase in saturated acids. One method of doing this is by checking the activity of the catalyst, for example by adding a small proportion of sulphur, 0·5–2 per cent, or selenium, or by using a partly spent catalyst, and by operating at rather high temperatures, 170–180°C. The "iso-oleic" acids formed may be elaidic acid or other isomers of oleic acid, and as these are solid acids of 30–40°C m.p., whereas oleic acid is liquid, the glycerides in which these isomers are constituents are of suitable consistency for margarine. A hydrogenated groundnut oil of this type contains about 25 per cent solid acids, 35 per cent "iso-oleic" acids, 35 per cent oleic acid and 5 per cent linoleic acid, and has often in some countries formed 90 per cent of the fat-blend. Groundnut oil hydrogenated to higher melting points and lower iodine values are also highly valued fats for margarine, and by varying the degree of hydrogenation and selectivity excellent plastic fats are obtained, for example m.p. 36°C, I.V. 66, m.p. 39°C, I.V. 59, and m.p. 42° C, I.V. 54. Hydrogenation of groundnut oil beyond 42°C m.p. is generally not used for table margarines, as in such fats with arachidic, behenic and lignoceric acids present in the glycerides in addition to the stearic acid formed by hydrogenation, and also present in the original oil, the proportion of high-melting glycerides makes the product too heavy on the palate and may reduce the digestibility. For incorporation in shortenings or in pastry fats in smaller proportions more highly hydrogenated products are often of value, for example of 48°C m.p., I.V. 40, and 52°C m.p., I.V. 28–30. Fully hydrogenated groundnut oil has a melting point of 66–68°C.

Olive Oil, as mentioned earlier, is used for margarine only under special conditions, and where, as in some Mediterranean countries, it has at times been stipulated, or politico-economic conditions have required, that olive oil only should be used, this oil has been hydrogenated to provide the solid fat-base for margarine. As olive oil contains only about 7 per cent linoleic acid and 10–12 per cent saturated acids, selective hydrogenation to the melting point required, i.e., 33–34°C, gives a grainy soft fat with rather poor consistency for margarine, but if hydrogenation is done with maximum iso-oleic formation, a fat free from linoleic acid, with iodine value 67–68 and about 30 per cent iso-oleic acid, will have a melting point of about 34°C and be suitable for margarine. It can also be used in mixture with liquid olive oil and the same oil hydrogenated to 42°C m.p., which is usually quite free from linoleic acid.

Hydrogenated Cottonseed Oil was until recently the most important edible vegetable fat in North America. During the last few years it has been exceeded by soyabean oil. The *ca.* 60 per cent linoleic acid in the original cottonseed oil can practically be eliminated by selective hydrogenation to an iodine value of about 60, when the fat has a melting point of 40–42°C. If hydrogenated under conditions favouring high "iso-oleic" acid formation firmer fats are obtained than under conditions suppressing isomerization, until at iodine values of 25–30 "iso-oleic" acid practically disappears. For margarine made entirely from hydrogenated cottonseed oil, as is often the case in certain countries, for example U.S.A., a melting point of 33–35°C is most suitable corresponding to iodine values of 72–74, and to get suitable plasticity and consistency hydrogenation conditions should favour production of 30–35 per cent iso-acids. In countries outside U.S.A. where other fats and oils are as a rule used together with hydrogenated cottonseed oil the latter is preferred of 40–42°C m.p., I.V. about 60, as low as possible in linoleic acid and with 15–20 per cent isomers. When used for shortening of wide plastic range and softish consistency the oil is usually hydrogenated very selectively and with suppression of isomerization to iodine values of 75–80 and then stabilized for melting point by an addition of 3–6 per cent of nearly fully hydrogenated cottonseed oil of 62–63°C m.p. Some manufacturers of rather firm edible fats or of pastry fats prefer straight hydrogenation to about 60 I.V., 40–42°C m.p. under moderately selective conditions, but it is, of course, possible by varying the conditions and degree of hydrogenation to obtain a wide variety of types of fats. The presence in these of mixed glycerides of palmitic, stearic and oleic acids is probably responsible for the excellent baking and texture quality of such hydrogenated cottonseed oil products.

Hydrogenated Soyabean Oil is mostly used in U.S.A. both in the manufacture of margarine and of shortening; its use in recent years exceeds that of cottonseed oil. The high content in liquid soyabean oil of linoleic acid, 50–55 per cent., and particularly the presence of 5–9 per cent of the triethenoid linolenic acid makes it necessary to adopt highly selective methods of hydrogenation with full control of isomerization to get for margarine a fat of suitable melting point, 33–35°C, and sufficient firmness to permit it to be used to the extent of 100 per cent. Such a fat has an iodine value of about 65–76 and may contain a small percentage of an isomer of linoleic acid, formed by hydrogenation of linolenic acid, which is stated to be responsible for the flavour reversion that sometimes is found in deodorized hydrogenated soyabean oil. Highly selective hydrogenation to eliminate all di- and triethenoid acids before any large increase in saturated acids is therefore desirable. Hydrogenated soyabean oils are made in the same types as those from cottonseed oil, but are of slightly higher melting points at equal iodine values, partly because there is relatively more stearic than palmitic acid among the saturated fatty acid radicals. The flavour reversion problem in part-hydrogenated soyabean oils frequently causes difficulties to manufacturers of shortenings, but less so to manufacturers of margarine, where the use of suitably treated milk lessens the risk. However, the reversion risk is small, in fats hydrogenated below iodine value 63, which is the type of fat mostly used outside North America. Fully hydrogenated soyabean oil melts at about 65°C.

Hydrogenated Sunflower Oil provides a range of fats similar in quality to those obtained from groundnut oil and cottonseed oil; in proportions of the various saturated acids they approach the former products, whereas in iodine value they are more like the latter for equal melting points. It is particularly in Eastern Europe, Russia, Hungary, Turkey, etc., that hydrogenated sunflower oil is a very important fat for margarine and is often used to the extent of 100 per cent in the fat charge, in which case it is hydrogenated to a melting point of 33–36°C, I.V. 74–77, usually with about 20-30 per cent "iso-acids", or it is used in mixture with liquid oil and a proportion hydrogenated to 42–44°C m.p., I.V. 60–64, which yields a mixture of excellent plasticity. Because of the rather high iodine value 127–137, of the liquid oil some manufacturers prefer to use instead of this a slightly and highly selectively hydrogenated oil, reduced in unsaturation to an iodine value of 100–110 and with minimal isomerization; this product is still liquid and keeps better than the natural liquid oil.

Hydrogenated Rapeseed and Mustardseed Oils became of some importance in several countries when for politico-economic or war reasons manufacturers of edible fats found themselves compelled to use these home-produced oils as their principal source of fatty raw materials. When judicious refining methods are used and particular care adopted for eliminating inorganic impurities, from admixtures to the seed, and organic sulphur compounds, from enzymatic decomposition of glucosides (see page 33), it is possible to produce the usual range of hydrogenated fats from practically liquid to very hard. The most favoured types are those hydrogenated to about 34°C m.p., I.V. 72, and about 42°C m.p., I.V. 60. It is not advisable to hydrogenate these oils to lower iodine values, as the principal unsaturated acid, which is present to the extent of *ca.* 50 per cent, is erucic acid, C′22, which when saturated forms the very high-melting behenic acid, m.p. 80°C, and di- and trisaturated glycerides with this acid are of low digestibility.

Other Vegetable Oils such as sesamé oil, corn oil, etc., can be hydrogenated on the principles described above, but they are mostly used as liquid oils. It should be mentioned that very unsaturated oils, as for example linseed oil, which are unsuitable for edible use, have occasionally in an emergency been hydrogenated to yield an edible fat, but the quality has not been satisfactory and the hydrogen consumption to reduce unsaturation adequately is very high compared with other oils. The iodine value of linseed oil hydrogenated to a melting point of 34°C is about 95–98, which is too high to ensure the disappearance of linolenic acid radicals. Even at 40–42°C m.p. the iodine value is high, 78–80, and unless very selective hydrogenation is adopted linolenic acid may still be present as well as an isomer of linoleic acid, formed by reduction of linolenic, which often causes reversion of flavour after deodorization. For reasonable safety against this linseed oil should be hydrogenated to 45–48°C m.p., I.V. 60–65, but the hardness, apart from flavour considerations, permits it to be used only in very small proportions, both in margarine and shortenings.

Hydrogenated Palm Oil.—Palm oil is mostly used in the non-hydrogenated form, but owing to its glyceride composition it has a tendency at temperatures of 25–30°C (see page 27) to segregate into a soft and a harder grainy fraction. This can be counterbalanced by suitable mixing with other fats, but can also be prevented by slight hydrogenation. As, however, the original fat has a melting point of 33–39°C, average I.V. 55, hydrogenation is done more to stabilize texture than to reduce unsaturation and is therefore regulated to favour isomerization of some of the liquid oleic acid radicals to solid iso-acids. By using a weak nickel catalyst or a nickel-aluminium catalyst a reduction of 5–7 units in iodine value raises the m.p. to 40–42°C and gives a still good plastic, but firmer fat of great stability against oxidation. For special purposes, such as pastry fats and shortenings, palm oil can be hydrogenated to a higher melting point. The high proportion of palmitic acid in the glycerides, as is also to some extent the case with hydrogenated cottonseed oil, makes it particularly good for baking purposes. Hydrogenation of palm oil has the further advantage, where white fats are wanted, to discharge by reduction with hydrogen the yellow and orange colour of the oil at an early stage in the process, thus lessening the usual bleaching treatment during refining.

Coconut and Palmkernel Oils.—These are the two most important vegetable natural fats for the manufacture of margarine; they are not often used there in the hydrogenated form. They are in their natural form only slightly unsaturated and little is gained by hydrogenation in stability or consistency. Coconut oil with iodine value 8–9 and m.p. 23–25°C will when saturated increase to m.p. about 34°C, and palmkernel oil, m.p. 27–29, I.V. 15–17, to a melting point of about 42 C, but both form hard, brittle, non-plastic fats and require complicated mixing with other fats and oils without giving the margarine fat-blend any advantage not obtainable with the non-hydrogenated fats. For certain purposes, however, such as cocoa butter substitutes, toffee fats, biscuits and cream icings these hydrogenated fats are greatly valued.

Inter- and Trans-Esterification.—These are the terms used for transfer or interchange of fatty acid radicals from one glyceride molecule to another. If, by way of example to illustrate the principle, it is assumed that a fat consisted of molecules of tristearin, C18 C18 C18, and triolein, C′18 C′18 C′18, which for many purposes is an unsuitable composition, it would be a great improvement if a regrouping of fatty acid radicals could be effected, so that the fat consisted of distearin monooleins, C18 C′18 C18, and monostearin diolein, C′18 C18 C′18, together with a residue of triolein. This process has in recent years been developed as an industrial possibility, and although the types of glycerides present are rarely as simple as in the quoted example, because fats and oils have a much more complicated composition and frequently consist predominantly of mixed glycerides, natural fats or mixtures of them can often be much improved in consistency for edible purposes by such a process. If the interchange takes place inside one particular fat the term interesterification is mostly used; if the interchange is of fatty acids from a mixture of two or more fats and oils the process is often referred to as transesterification; but admittedly the terms are used rather indiscriminately and probably both interchanges take place in mixtures of fats. These interchanges which in simple mixtures follow closely mathematical laws can by use of suitable catalysts be effected at moderate temperatures in an hour or less, thus permitting new fats of more suitable melting points and texture characteristics to be obtained. With about 0·2 per cent sodium or potassium glyceroxide as catalyst the reaction takes place at 140–160 C, with sodium methoxide at 100–120°C. The fat must first be carefully neutralized, and during the interesterification process a vacuum is maintained to keep the fat dry, while a current of nitrogen is bubbled through the mixture. When the process is finished, as indicated by the change in melting point, the mixture is cooled to *ca.* 90 C and the catalyst and traces of soap removed by washing with hot water; the fat is then bleached and deodorized.

Although patents indicating the possibility of this acid interchange date back to 1920 [76] [77] and 1924 [78], the conditions described there necessitated working at rather too high temperatures and with catalysts which tended to discolour the fat. Discovery of more active catalysts permitting lower temperatures, and introduction of better plant of stainless steel, has made the process an important one, particularly for modifying fats for the manufacture of margarine. Although by mixing hard fats of high melting point with low melting fats or with liquid oils the melting point of the mixture is lower, as ascertained by the open capillary tube method, and the fat may become softer and plastic, the high-melting glycerides are still there, though masked, and they remain solid on the palate and "heavy" and less digestible. If, for example, a fully hydrogenated fat such as soyabean oil, consisting largely of tristearin, is mixed with twice the quantity of a liquid oil such as triolein, the mixture has a combined melting point of about 56°C, although plastic. If on the other hand the mixture is transesterified and fatty acid radicals interchanged, a new fat of melting point about 35°C with only 10–15 per cent tristearin and triolein and much higher proportions of di- and monosaturated glycerides is obtained. This is of higher digestibility and better plasticity.

A survey of this process has been given recently by VAN LOON [79] and a number of patents have been taken out during the last fifteen years. Some of these [80] describe transesterification at relatively low temperatures to enable the high-melting glycerides, for example tristearin, to crystallize out during the process. This method is also described in the literature by ECKEY [81]. As the consistency of a fat is conditioned by the proportion of solid glycerides at the particular temperature, and as it is desirable that these solid glycerides should have melting points below or only slightly above body temperature it is clear that trans- or interesterification is very useful to achieve this result. Tristearine in its stable form melts at *ca.* 71°C, tripalmitin at 65°C, whereas distearin monoolein melts at 38·5°C and 43°C according to its configuration, monostearin diolein at 23·5°C, dipalmitin monoolein at 34·5° and 36°C and monopalmitin diolein at 19°C.

Palm oil which because of its glyceride composition (see page 27) softens considerably at 25–30°C can by interesterification develop a glyceride composition where this drawback is largely overcome and the trisaturated glycerides eliminated. Highly hydrogenated whale and fish oils are transesterified with coconut oil and with liquid oils and give fats with quite different characters from those of simple mixtures. Many other combinations of fats or of fats and oils are possible to yield harder or softer transesterified products according to the fatty acid composition of the constituents. GOODING [82] uses the process for making very hard fats of moderate melting point similar to cocoa butter from hydrogenated coconut and palmkernel oil and liquid oil. By an analogous process butyric acid can be made to exchange position with stearic or palmitic acid in glycerides of tallow, thus producing an approach to an imitation of certain butterfat glycerides from a mixture of beef fat and butyric acid.

Polymerized Oils.—In the same way as drying oils by heating in the absence of air can have their iodine value reduced and their viscosity increased by polymerization certain oils containing highly unsaturated fatty acid radicals, such as whale oil and fish oils, can by a similar treatment be partially polymerized and thereby largely lose their tendency to develop fishy flavour and can acquire better resistance to oxidation. The process is operated either continuously or in batches in stainless steel vessels under vacuum and at 250–280°C on neutralized clarified oil, generally while a current of inert gas or steam bubbles through the oil. For edible purposes the treatment is regulated to yield principally dimers, and with whale oil a reduction in iodine value to *ca.* 90, with herring oil *ca.* 100, is usually sufficient to eliminate fishy flavour and causes only a moderate increase in viscosity. At the same time there appears often to be some other molecular rearrangement of the interesterification type, as some solid fine-grained crystalline glycerides separate out. These can easily be filtered off if desired, as is the case when the oil is used for canned preserved fish in place of olive oil. After polymerization the oil must be given a complete refining and deodorization treatment.

The polymerization process is much cheaper than hydrogenation, and after filtration or settling to remove the solid-glyceride "cloud" the oil has the character of a liquid oil, which is essential for canning. Hydrogenation, which is the only other process known for making these oils of sufficiently good flavour for edible use, converts them into solid fats before fishy flavour and proneness to oxidation is eliminated.

Food manufacturers are, however, justly reluctant to use these polymerized oils, except in very small proportions, as their physiological utilization is doubtful. The digestibility of the oil decreases with increasing polymerization as it appears from tests that the polymerized part of the oil is not absorbed; there appears also to be secondary effects [83]. It seems, therefore, that the best way of utilizing marine animal oils for edible purposes is by giving them an appropriate hydrogenation treatment. Semi-drying vegetable oils, such as soyabean oil, can also show a slight indication of polymerization if treated at high temperatures, above 235°C, during refining.

Synthetic Fats.—Although hydrogenated fats are sometimes described as synthetic fats this term usually applies to fats made by combining natural fatty acids with other alcohols than glycerol, or to fats from synthetically built up fatty acids combined with glycerol made by fermentation or by synthesis. The first type is often called "Esteroils", the second synthetic glycerides. Normally these fats are not of much importance in the edible fats industry, but twice under war economy they have been used in Germany and therefore become more than a technical curiosity.

Esteroils were made in Germany during the 1914-1918 war [84] by esterifying by-product fatty acids from the refining and glycerine industries with ethylene glycol or with ethyl alcohol; only the latter found large scale application then and also during the recent war. Clinical tests showed that the ethyl ester of natural fatty acids was physiologically acceptable, but the industrial use was limited, because the flavour quality was poor, as deodorization had to be done at relatively low temperature, 120–130°C, to avoid hydrolysis. The fat also showed a tendency to hydrolize when used in margarine. The esters of this monovalent alcohol with fatty acids have not the complex composition of the natural mixed glycerides and are softer and of poor consistency; their use in margarine blends was therefore limited to 10 per cent; they have shown some value as stabilizers of margarine emulsions.

For the production of synthetic glycerides the fatty acids were made either by catalytic oxidation of paraffin hydrocarbon chains of suitable length or by oxidation of a fraction of the hydrocarbons obtained in the Fischer-Tropsch process, which yielded fatty acids of many different chain lengths from C4 to C28. Distillation of these acids gave a medium fraction of fatty acids, about 60 per cent, of chain lengths C10 to C20, which by esterification with glycerine gave the synthetic fat for margarine. Whereas, however, natural fatty acids have an even number of carbon atoms only in the chains, these synthetic acids contain about equal proportions of even and odd numbered chains and some of these may be branched chain acids. Medical opinion is sceptical and critical about the physiological value and metabolism of these acids, and their esters with glycerol must still be considered with suspicion for edible purposes [85] [86] [87] [88] [89]. The margarine fat, consisting of this synthetic fat entirely, had a melting point of about 35°C and an iodine value of 10–15; sometimes it was slightly hydrogenated to improve colour and flavour, but even when fresh it had a peculiar harsh flavour which was only partly covered by the various ingredients in the margarines. Like the ester oils the synthetic fat has a noticeable emulsifying effect. Apart from the physiological aspect the cost of manufacture will at ordinary times make the use of these artificial products unattractive.

Synthetic fats have also been produced by the action of microorganisms, for example, various moulds and *torulaceae*, but although nutritionally good fats can be produced in this way yields are at present small and the economics uncertain, and the process is still in the research and development stage. The subject of synthetic fats of the different kinds has been dealt with by P. N. Williams in *Chemistry and Industry* [90].

8. COMPOSITION OF BLENDS

From this large range of fats and oils the manufacturer makes his selection with due regard to their cost and to the quality and character of the margarine. Some blends are composed of one or two, some of several fats and oils. The aim is to obtain a blend of high stability, suitable consistency, wide plasticity range with minimum change in firmness at varying temperatures. The consistency and plasticity of the margarine is related to several factors, one of which is the state of the emulsion and therefore not dependant on the fat alone, but other factors depend on the fat-blend, its glyceride composition, the ratio of solid and liquid glycerides at changing temperature, and the crystal formation of the solidified fat.

Plasticity and spreadability are important properties of margarine, not only where it is used for spreading on bread, but also where as a shortening ingredient it is used for interleaving cakes and pastry. For a fat to be plastic it must consist of a solid and a liquid phase, and the ratio of the two phases and the crystalline character of the solid phase determine the consistency and firmness. As fats and blends of fats and oils consist of mixtures of a number of different glycerides with different melting points, the ratio of solid and liquid glycerides varies with the temperature. The ideal fat would be one that shows no change in the ratio over a wide range of temperatures, according to climatic conditions, and in which at those temperatures the ratio is such that there is present sufficient of solid particles, and in such fine dispersion, as to form a network or skeleton to enmesh the liquid phase and hold it by cohesive forces to prevent flow at stresses below those considered appropriate for the desired consistency. These stresses also depend on the crystal formation of the solid phase which can be regulated to a considerable extent by the churning and cooling technique during processing.

To obtain an indication of the suitability of a fat or fat/oil mixture as a basis for a plastic product it is therefore important to gain some information about the ratios of solid and liquid components in the appropriate temperature range. The two methods which have found practical application are those of calorimetry and dilatometry.

The calorimetric method consists in measuring the latent heat of fusion in fat at the temperature at which the phase ratio is to be determined. If it is assumed that all solid glycerides have the same heat of fusion—this is approximately correct and sufficiently exact for a practical test, even if not for research—the amount of solids present at the particular temperature can be calculated. This method is, however, rather cumbersome for routine use, and if the phase ratio is required over a range of temperatures a number of tests are needed for one fat. Modifications of this method have been described by BAILEY *et al.* [91] [92] [93] [94] and by SÖLTOFT [95].

The dilatometric method is simpler and more informative. It is based on the temperature/volume (T/V) diagram of the fat over the range of temperatures at which the fat changes gradually from solid to liquid, in practice usually from 10°C to a few degrees above complete melting, and when from this diagram a graph is drawn which represents the dilatation due to melting a curve is obtained, the melting-dilatation curve, which gives an indication of the ratio of solid and liquid glycerides present at the various temperatures.

The increase in volume of a fat on heating is due partly to the usual thermal expansion, partly to special dilatation when glycerides melt. When a single triglyceride is slowly heated the T/V curve will appear as in Fig. 1, where the increase in volume from T_1 to T_2 is due to thermal expansion of the solid glyceride; the volume increase at T_2 is due to melting dilatation at that temperature, and the increase in volume of the liquid glyceride from T_2

to T_3 is again due to thermal expansion. If the thermal expansion is deducted from the total expansion the graph represents the melting dilatation curve and will appear as in Fig. 2; there is no melting dilatation between T_1 and T_2 or between T_2 and T_3. Below T_2 the glyceride is solid, above it is liquid. If two triglycerides are present the melting is not completed at one temperature, and as the two triglycerides may form eutectic mixtures and show inter-solubility the dilatation graph may show a number of transition points where melting dilatation takes place, Fig. 3. Above T_4 no further melting takes place.

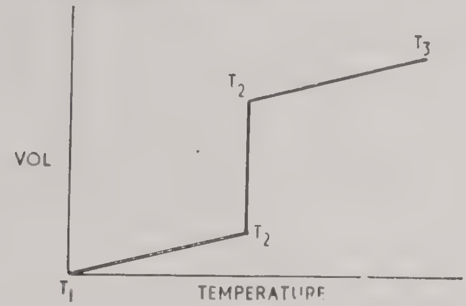


Fig. 1. Temperature/Volume graph for thermal expansion of triglyceride.

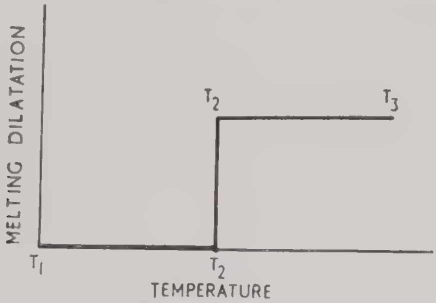


Fig. 2. Melting dilatation graph for triglyceride.

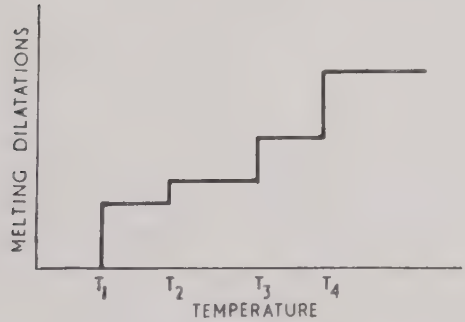


Fig. 3. Melting dilatation graph for mixed glycerides.

Fats consist, however, of a number of triglycerides, some liquid far below 0°C, some melting at temperatures as high as 60–65°C and at intermediate temperatures; consequently their T/V curves and their dilatation graphs do not show the sharp inflections at definite temperatures as in the theoretical diagrams above, partly because some of the glycerides exist in polymorphic forms, partly because there may be intersolubility between them. If dilatometric methods for studying the phase changes in fats have to be very accurate, as in research work, they take a long time—several days—to complete as temperature increments must be small and after each a period of hours is required to stabilize the phases; but to provide guidance for practical purposes tests made under standardized conditions can be completed in a few hours. Dilatometric studies of fats have been recorded by NORMAN [96], HOFGAARD [56], BAILEY *et al.* [97] [98] [99] [100], CRAIG *et al.* [101], SINGLETON and GROS [102] and SÖLTOFT [95]. Their application to practical process control for hydrogenation of fats and for composing fat-blends for margarine and shortening is usually subject to modification of the test technique to suit the particular purpose.

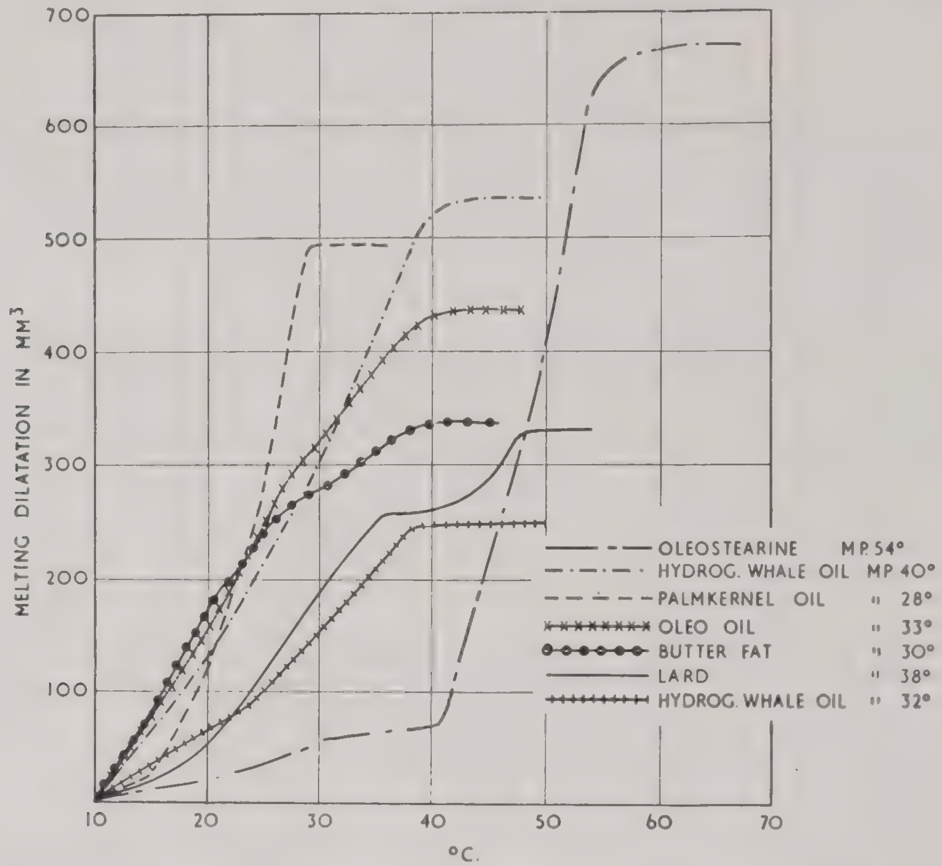


Fig. 4. Melting dilatation of 10g fat from 10°C in mm³.

Fig. 4 shows melting dilatation graphs for a number of fats used in the manufacture of margarine. The tests were made on 10 g of fat and measured in mm³ at temperatures from 10 -60 C. When the curve becomes horizontal all the glycerides are in the liquid form, but a few degrees below that temperature the proportion of solid glycerides is so small that the fat flows, a point usually determined as the "slip" melting point. The graph shows that some fats melt over a rather narrow range compared with others.

Dilatation graphs are frequently, for the sake of convenience of interpretation, drawn so that they show the melting dilatation that takes place from various temperatures to complete melting. Fig. 5 shows a graph for some fats drawn in this way. The curve, for example, for hydrogenated whale oil 52°C m.p. shows that between 10°C and 30°C there is practically no change in the melting dilatation, i.e., in the solid/liquid phase ratio; above 36°C some of the solid glycerides melt, and as the temperature increases melting proceeds, until at 53°C all the glycerides are liquified. The sloping curves of other fats such as coconut oil and palm oil indicate a steady more or less rapid change in phase ratio between 10°C and complete melting.

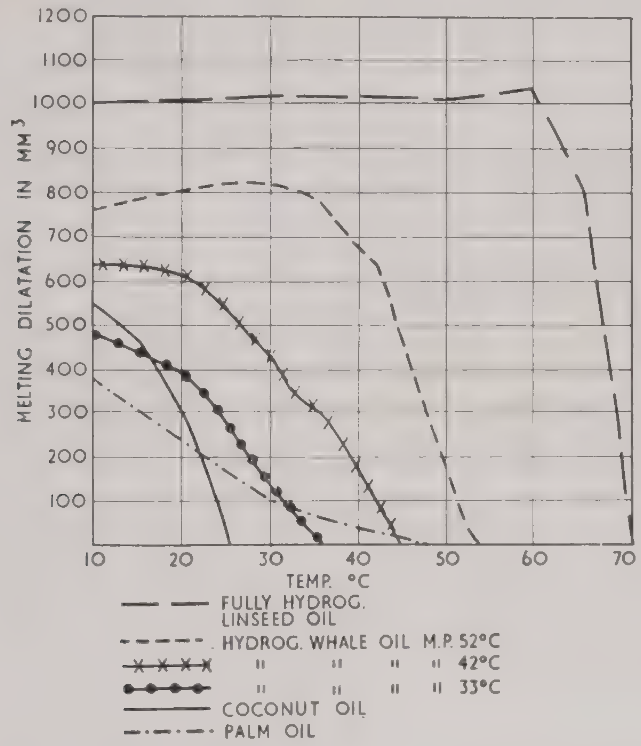


Fig. 5. Melting dilatation of 10g fat from various temperatures to complete melting.

There is no general standard type of dilatometer, but most of those used in the edible fat industry consist of a glass bulb for holding 2–10 g of fat and a suitable quantity of a non-volatile indicator liquid. The bulb is connected with an open capillary tube with calibrated divisions to enable readings to be made with an accuracy of one cubic millimetre or 1/1000 ml. The fat fills the upper half of the bulb and by its expansion and melting dilatation during heating forces the indicator liquid, glycerine, mercury, etc., which fills the lower part of the bulb and the bend connecting bulb and tube, to rise in the capillary indicator tube. The increase in volume, less that caused

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by thermal expansion, which with sufficient accuracy for this purpose can be assumed to be the same for liquid and solid fats, gives the melting dilatation at the various temperature intervals and the residual dilatation from various temperatures to complete melting; this figure recalculated for 10 g fat is used in the diagrams in the illustrations.

Figs. 6*A*, *B* and *C* illustrate three dilatometers; it will be seen that they are similar in type. 6*A* is HOFGAARD's dilatometer [56] with special closure for the bulb; measurements were made on 7–10 g fat and 5–7 g mercury were used as indicator liquid; the capillary tube was 360 mm, the diameter of the bulb *ca.* 18 mm.

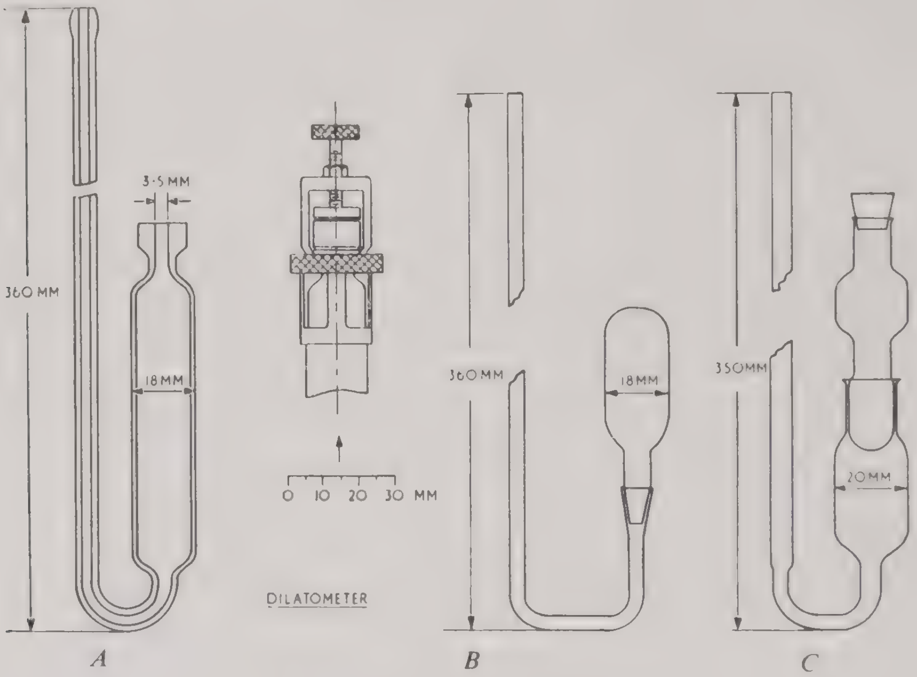


Fig. 6*A*, *B* and *C*. Dilatometers.

6*B* is the instrument used by WILLIAMS [103]; the capillary is in this case also 360 mm and the width of the bulb 18 mm; the bulb is joined to the capillary tube by a ground glass joint; tests are made on 6–8 ml. fat, air-free water is used as indicator liquid.

6*C* is a dilatometer much used in the edible fats industry; the capillary is *ca.* 350 mm long, the width of the bulb about 20 mm. The closure of the bulb is made by a special hollow glass stopper fitting into a ground glass seating. The stopper is filled with shot to steady the instrument in the water-bath; coloured air-free water is used as indicator liquid.

For all tests it is essential that the fat is vacuum treated in molten form to drive out air and afterwards cooled and reheated under standardized conditions. For details of the technique of the test the reader is referred to the various references about dilatometry.

The diagrams also indicate the approximate proportion of solid glycerides present at any particular temperature within the range of the diagram, based on the assumption that all completely solid fats, usually a complex mixture of a number of mixed glycerides, on changing into completely liquid glycerides show a melting dilatation of 1000 mm^3 per 10 g. This is not strictly correct as the melting dilatation of individual glycerides vary to some extent with their chemical composition, but as pointed out by ANDERSEN [104], it has been found on the basis of 30 years' experience with a large number of fats, natural and hydrogenated and completely solid at − 10° to − 15°C, with their complex mixture of many individual mixed and simple triglycerides, that for practical guidance in the edible fats industry the assumption is permissible.

The diagrams drawn on the principle shown in Figs. 5 and 7 can then also be used for showing the approximate phase ratio at different temperatures. It will be seen, for example in Fig. 5, that fully hydrogenated linseed oil, predominantly tristearin, shows a melting dilatation for 10 g of approximately 1000 mm^3 from any temperature between 10°C and 60°C and therefore consists of 100 per cent solid phase. At 66°C the dilatation is 900 mm^3 and the fat contains 90 per cent solid and 10 per cent liquid phase. After 66°C the fat rapidly changes in fat ratio and at 70·3°C is completely liquid. The same diagram shows from the dilatation curve for coconut oil that at 10°C it contains 55 per cent solid phase which rapidly diminishes by increasing temperatures, is about 30 per cent at 20°C and that the fat is completely liquid at 25°C.

While the graphs and the indicated percentages of solids at the various temperatures in Figs. 5 and 7 are from the author's own experience, a table of dilatometrically estimated percentages of solids in fats at different temperatures is given by BAILEY [105]. They are as follows:

TABLE IX.—*Percentage Solid Phase in Various Fats at Different Temperatures*

Temp. °C	*Butter*	*Lard*	*Premier jus*	*Oleo*	*Coconut Oil*	*Palm-kernel Oil*	*Palm Oil*
50	—	—	—	—	—	—	—
45	—	2·5	13	—	—	—	—
40	—	5·5	22	2·5	—	—	—
35	1·5	7·5	28·5	8·5	—	—	3
30	5·5	14·5	35·5	13·0	—	—	6·5
25	9·5	26·5	46	18·0	6	18	11·0
20	21·0	32·5	55	28	34·5	38	21·0
15	34	37·5	—	40	49	48	31·0
10	40	—	—	51	55	53·5	42·5
5	43	—	—	—	—	—	—
0	—	—	—	—	—	—	—
m.p.	38°	48·5°	50°	42°	26°	29°	38°

In practice it has been found that fats which contain from 15 to 30 per cent of solid glycerides show good plasticity for spreadable fats, and the ideal would be to have this ratio between the material temperatures, usually 10 to 30 C, with a gradual decrease in the solid phase until the complete liquid state at 37°C. If the ratio of solid glycerides is more than 35 per cent the fat may show some plasticity, but will be too tough for table margarine; if the ratio is below 10–12 per cent the fat is too soft and greasy.

Fig. 7 shows melting dilatation/temperature graphs for butter fat, oleomargarine and two margarine blends as well as an imaginary ideal fat-blend for British climate. There is a similarity in the phase ratio changes of butter fat and oleomargarine over this range of temperatures. To obtain similar changes margarine blends have to be composed of mixtures of fats or fats and liquid oils. None of the fats shown reach the ideal; it is well known that butter fat is rather too hard below 10°C and to soft above 24°C; but judicious mixing, with due regard to the cost aspect, can help to produce a margarine fat of suitable plasticity and consistency characteristics, adjusted for climatic conditions.

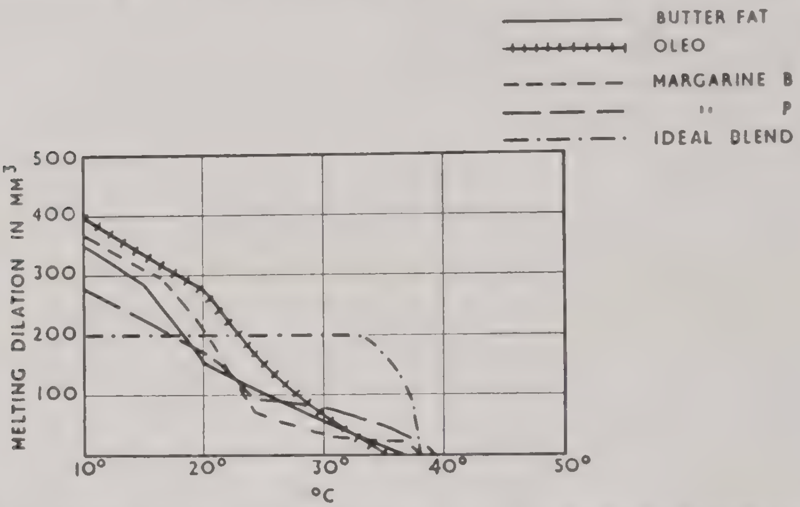


Fig. 7. Melting dilatation curves for butter, oleo, 2 margarines and ideal blend.

The percentage of solid phase in two samples of butter fat and two samples of margarine fat-blend at various temperatures were found to be:

Table X

	Temperature °C				
	10°	15°	20°	25°	30°
Butter fat I	34%	27%	16%	11%	5%
,, II	38	31·5	16·5	9·5	5
Margarine fat I . . .	37	30·5	22	8	4
,, II . . .	28	24	17	9·5	6·5

These fats are all rather too soft for most purposes at 25°C and nearly fluid at 30°C. A desirable solid phase content in temperate climates would be about 20 per cent at temperatures from 0° to 32–33°C with rapid reduction in solid phase until complete fluidity at 37°C. Such an ideal fat, from the point of view of glyceride composition, is not at present a practical possibility, but in most cases it is possible, except under special raw material supply difficulties, to compose blends which in phase ratios come within the limits found in butter fat. It is, however, often a decided advantage for the margarine manufacturer to arrange blends with phase ratios more suitable to meet climatic and seasonal conditions than can be done with a "natural" fat like butter fat. The "ideal" fat would ensure no change in phase ratio over the material range of temperatures and thus no change in consistency, and therefore no need for seasonal adjustment in composition.

As mentioned, there are several approximations in computing the percentage of solid glycerides present at the different temperatures, but they are not material for practical purposes and these calculations are mostly unnecessary as the manufacturer of plastic fats gets his required guidance from the shape and dimensions of the graphs showing the residual melting dilatation from the relevant temperatures to complete melting.

Although in the composition of fat-blends there are guiding characteristics of fats and oils as described, melting point, iodine value, glyceride composition, etc., the wide choice of materials, in normal circumstances, offers the manufacturer the possibility of numerous variations and combinations in which cost of materials and process, experience, consumer preference and type of product required is taken into consideration. At one time the composition of fat-blends was a closely guarded factory secret based largely on empirical knowledge. The application of science to this feature of the process has placed formulation on a more rational basis.

Formulae of fat-blends for various types of margarines are given below as examples. As the melting points of animal and hydrogenated fats vary, the former from selection of raw materials and fractionation, the latter from the degree and selectivity of hydrogenation, the melting points of the fats used in the formulae are shown as determined by the open capillary tube slip point method. The liquid oils are largely interchangeable as far as consistency is concerned, but vary considerably in susceptibility to oxidation because of differences in unsaturation and type of acyl radicals.

Predominantly Animal Fat Margarine:

1.	Oleomargarine, 30°C m.p.	60%
	Neutral lard, 38°C m.p.	30
	Oil	10

2.	Oleomargarine, 30°C m.p.	40%
	Premier jus, 46°C m.p.	20
	Neutral lard, 38°C m.p.	15
	Oil	25

3.	Oleomargarine, 30°C m.p.	40%
	Premier jus, 46°C m.p.	15
	Neutral lard, 38°C m.p.	15
	Coconut oil, 24°C m.p.	10
	Oil	20

Vegetable Margarines based on Coconut or Palmkernel Oil:

1. Coconut oil, 24°C m.p.	50%
Hydrog. veget. fat, 42°C m.p.	25
Oil	25

2. Palmkernel oil, 28°C m.p.	50%
Hydrog. palm oil, 44°C m.p.	20
Oil	30

3. Coconut oil, 24°C m.p.	60%
Hydrog. palm oil, 44°C m.p.	20
Oil	20

Vegetable Margarines based on Hydrogenated Fat:

1. Hydrog. groundnut oil, 32–34°C m.p.	70%
Coconut oil, 24°C m.p.	10
Oil	20

2. Hydrog. cotton seed oil, 28°C m.p.	85%
,, ,, ,, 42–44°C m.p.	15

3. Hydrog. sunflower oil, 44°C m.p.	20%
,, ,, ,, 32°C ,,	60
Oil	20

4. Hydrog. rapeseed oil, 42°C m.p.	10%
,, ,, ,, 32°C ,,	38
Premier jus, 46°C m.p.	10
Oil	42

Mixed High-Grade Animal and Vegetable Fat Blends:

1. Oleomargarine, 30°C m.p.	20%
Lard, 38°C m.p.	10
Hydrog. gr. nut oil, 34°C m.p.	50
Oil	20

2. Oleomargarine, 30°C m.p.	40%
Lard, 38°C m.p.	15
Hydrog. gr. nut oil, 34°C m.p.	20
Oil	25

3. Oleomargarine, 30°C m.p.	50%
Lard, 38°C m.p.	25
Hydrog. gr. nut oil, 38°C m.p.	10
Oil	15

4. Oleomargarine, 30°C m.p.	35%
Hydrog. gr. nut oil, 33°C m.p.	33
Hydrog. gr. nut oil, 38°C m.p.	12
Oil	20

Mixed Animal and Vegetable Fat-blends based on Hydrogenated Whale Oil and Coconut Oil:

1. Hydrog. whale oil, 44–46°C m.p.	25%
Coconut oil, 24°C m.p.	50
Oil	25

2. Hydrog. whale oil, 34°C m.p.	70%
Coconut oil, 24°C m.p.	15
Oil	15

3. Hydrog. whale oil, 44–46°C m.p.	15%
Hydrog. whale oil, 34°C m.p.	45
Coconut oil, 24°C m.p.	20
Oil	20

4. Hydrog. whale oil, 44–46°C m.p.	20%
Palm oil, 38°C m.p.	15
Coconut oil, 24°C m.p.	20
Palmkernel oil, 28°C m.p.	20
Oil	25

5. Hydrog. whale oil, 40–42°C m.p.	45%
Palmkernel oil, 28°C m.p.	15
Coconut oil, 24°C m.p.	15
Oil	25

Various Blends for Special Margarine for Flaky Pastry:

1.	Oleomargarine, 30°C m.p.	25%
	Premier jus, 46°C m.p.	25
	Oleostearine, 54°C m.p.	12
	Lard, 38°C m.p.	20
	Oil	18

2.	Premier jus, 46°C m.p.	35%
	Oleostearine, 54°C m.p.	20
	Oil	45

3.	Premier jus, 46°C m.p.	25%
	Hydrog. palm oil, 46°C m.p.	25
	Hydrog. gr. nut oil, 34°C m.p.	10
	Oil	40

4.	Oleostearine, 54°C m.p.	25%
	Hydrog. whale oil, 46°C m.p.	30
	Oil	45

Some Blends for Margarine for Soft Cakes and Short Pastry:

1.	Hydrog. whale oil, 44–46°C m.p.	20%
	Hydrog. whale oil, 34°C m.p.	30
	Coconut oil, 24°C m.p.	30
	Oil	20

2.	Premier jus, 46°C m.p.	25%
	Coconut oil, 24°C m.p.	35
	Oil	40

3.	Hydrog. palm oil, 42°C m.p.	25%
	Palm oil, 38°C m.p.	30
	Hydrog. gr. nut oil, 34°C m.p.	20
	Oil	25

4.	Hydrog. gr. nut oil, 42°C m.p.	25%
	Lard, 38°C m.p.	20
	Oleomargarine, 30°C m.p.	35
	Oil	20

5.	Hydrog. gr. nut oil, 34°C m.p.	70%
	Coconut oil, 24°C m.p.	10
	Oil	20

6.	Hydrog. gr. nut oil, 42°C m.p.	30%
	Coconut oil, 24°C m.p.	20
	Palmkernel oil, 28°C m.p.	20
	Oil	30

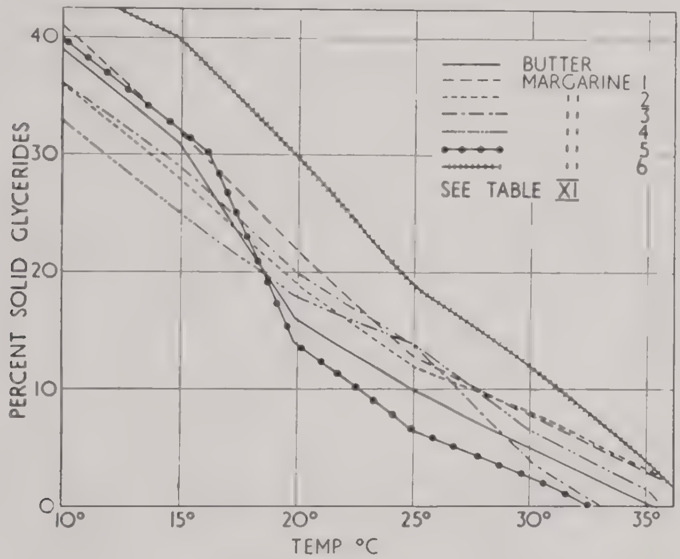


Fig. 8. Percentage solid glycerides in butter and some margarines at various temperatures.

Blends 1 and 2 are particularly suitable for soft cakes where high "creaming" power is required; blends 3, 4 and 5 for short pastry and blend 6 for general cake-making properties.

Fig. 8 shows graphs in which the percentage of solid glycerides in a sample of butter and in six samples of margarine is plotted against temperature.

Table XI gives these percentages as well as the compositions of the fat-blends. Margarine blend 6 is composed specially for cake making.

TABLE XI

	Temperatures °C						
	10°	15°	20°	25°	30°	35°	40°
Butter . .	39%	31%	16%	10%	5%	0·5%	—
Margarine 1 .	41	32	22	13	8	3	—
,, 2 .	36	28	19	12	8	3	—
,, 3 .	36	29	20	14	4	—	—
,, 4 .	33	25	18	14	6·5	1·5	—
,, 5 .	40	32	14	6·5	2·5	—	—
,, 6 .	44	40	30	19	12	4·5	—

Compositions of Margarine Blends

	1	2	3	4	5	6
Hydrog. whale oil, 45°C m.p.	10%	10%	—	—	—	—
,, ,, 34°C ,, ...	—	—	—	60%	—	—
,, ,, 42°C ,, ...	—	—	—	—	20%	20%
Premier jus, 46°C m.p.	—	—	—	—	—	20
Lard, 38°C m.p.	—	—	—	—	—	20
Hydrog. ground nut oil, 34°C m.p. . .	20%	—	70%	—	—	—
Palm oil, 38°C m.p.	30	50%	—	—	—	—
Palmkernel oil, 28°C m.p.	30	25	—	—	—	—
Coconut oil, 24°C m.p.	—	—	—	20%	55	10
Liquid oil	10	15	30	20	25	30

9. PREPARATION OF THE FAT-BLEND

Modern margarine factories of medium or larger capacity have frequently a department for refining, i.e., neutralizing, bleaching and deodorizing vegetable fats and oils as well as hydrogenated oils. Natural animal fats such as premier jus, oleo, oleostearine and neutral lard are usually obtained from outside producers in good edible quality which does not require refining. Where a refinery is attached to the margarine works the production of the former is synchronized with the demand from the latter so that freshly deodorized raw materials are available and need to be stored for a short time only in liquid condition. Preferably the storage period should not exceed 48 hours and storage vessels of stainless steel, aluminium, enamelled or tinned steel are to be preferred to ordinary steel, but the cost is high and the plain steel vessels are therefore more common. In recent years various hard plastics coatings for steel vessels have been introduced; great care should be taken that they are quite inert towards oils and also that they do not impart any flavours to the oil. Where a refinery is not attached to the margarine factory the deodorized fats and oils are frequently, if the quantities justify it, received in liquid form in road or rail tank waggons. There is a great advantage in storing the materials in the liquid form, because of the ease and economy of handling and transport for subsequent processing and mixing.

Storage tanks are often placed in rooms kept at sufficiently high temperature to maintain the contents liquid, except in the case of high-melting hydrogenated fats, which should be stored in tanks with heating coils or jackets. Some manufacturers prefer to store all fats melting above 40°C in solidified form, particularly if the storage period exceeds 3–4 days, and then remelt the material shortly before usage. Most fats and oils when stored above 50 C show after 2–3 days a tendency to oxidation, as shown by the formation of peroxides (Lea test, etc.).

Animal fats and purchased fats and oils are usually packed in barrels or steel drums of different constructions and stored at warehouse temperature in the packages. They are then melted out either separately as individual fats for subsequent mixing or in the proportions of the desired formula for the blend.

If the material is solid and packed in wooden barrels it is removed from the container as a block and either chopped into pieces and placed in jacketed tin-lined steel tanks for melting, or sliced on a machine with revolving knives, placed above the melting-tank. Another method is to place the solid block of fat on a grid of 1 in. steel or stainless steel pipes above the tank; the water circulating through the pipes melts the fat where it contacts the pipes, the melted fat drains into the tank together with pieces of solid fat passing through the grid and melting is completed in the jacketed tank which is often provided with stirrers. If the material in the barrels is semi-fluid these are often placed in hot air chambers and thus warmed for easier removal of the contents. The heat transfer from air through the wood of the barrel is too slow for this method to be used for firm fats. In no circumstances should steam or hot air be blown into the barrels for melting contents of edible fats.

If the fat is packed in steel drums or steel barrels, the container, well closed, is sometimes submerged in hot water tanks or placed in a steam heated chamber for melting. If the steel container is of the removable-head type and the contents can be slid out as a block they can be treated as when received in wooden barrels.

Fig. 9 shows a jacketed melting tank with a hot water grid on top.

As mentioned, some margarine manufacturers receive their refined fats and oils in liquid form in tank wagons; this method entails in certain circumstances some risk, as the contents must be kept some degrees above the melting point to avoid setting or separation of high-melting constituents, and are frequently exposed to mixing with air by swirling and shaking during transport. However, where transit is rapid, shunting minimal and tank wagons kept scrupulously clean and well drained after each journey to avoid contamination with layers of old fat exposed in films to air, the system is practical and very economical in both handling and transport cost. The same tank wagons should not be used for transportation of crude oils.

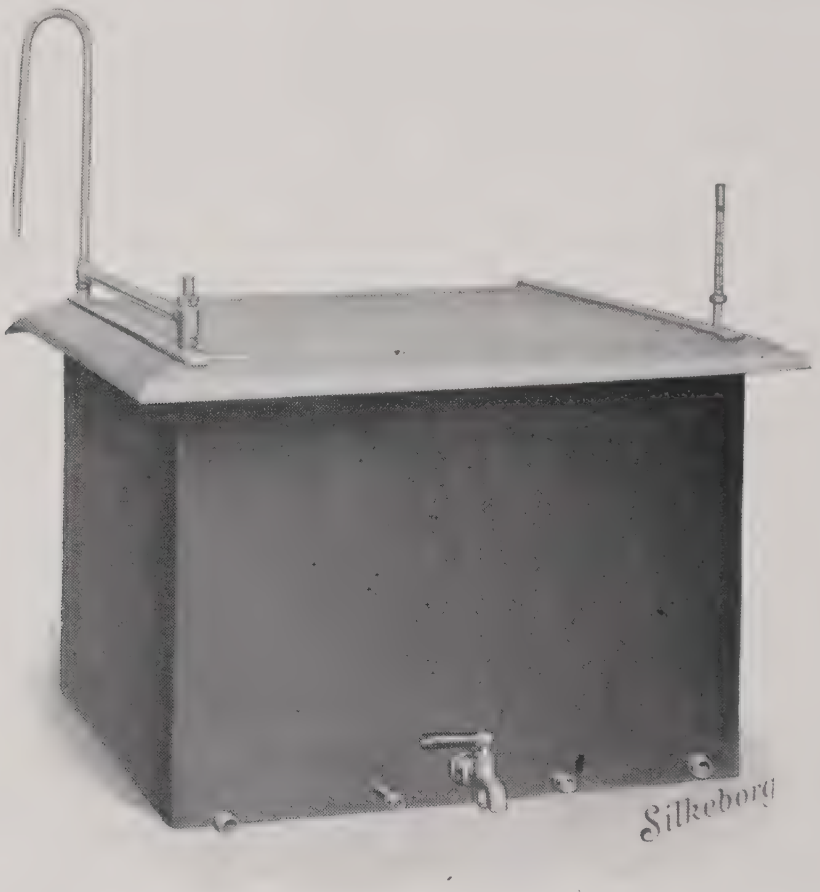


Fig. 9. Melting tank with grid (Courtesy: *Silkeborg Engineering Works*).

When barrels or drums have been emptied they should be steamed out with direct injection steam to remove remnants of the contents, generally amounting to 0·2–0·5 per cent. The fatty matter is separated from the condensed steam and returned to the refinery or disposed of for technical purposes. After steaming the containers should be blown dry by a current of hot air. For edible fats wooden barrels should be of hardwood and steel drums should be tin lined or coated with a suitable plastic. Stainless steel drums are too expensive, aluminium drums too weak and difficult to clean with alkali, and enamelled linings too easily cracked and damaged during usage.

Melting tanks are placed on a floor below that on which solid fats are broken up or placed on a melting grid; a metal tray under the grid permits the fat when softened or liquefied to drain to the melting tanks. These, when of 1–2 tons capacity, are usually oval or rectangular and jacketed, the inner container made of tinned or stainless steel, the outer of ordinary steel. Hot water in the jacket can be heated by steam injected from a perforated coil under the bottom of the inner tank, which is usually arranged with a slope towards the outlet for better draining when emptying. The jacket has also an inlet and overflow pipe for water as well as a drain. Steam for direct heating of the jacket is deprecated as it may damage the fat through local overheating; the steam-heated water is kept in brisk motion by the injected steam and heat transfer thereby accelerated. The amount of heat required for melting a solid fat such as premier jus should not, even in cold weather, exceed 80,000 Calories per ton, including radiation losses; but many fats require less as they consist only partly of solid glycerides.

Small rectangular melting tanks of the type shown under the grid in Fig. 9 are usually stirred by hand. Larger melting tanks, as shown in Fig. 10

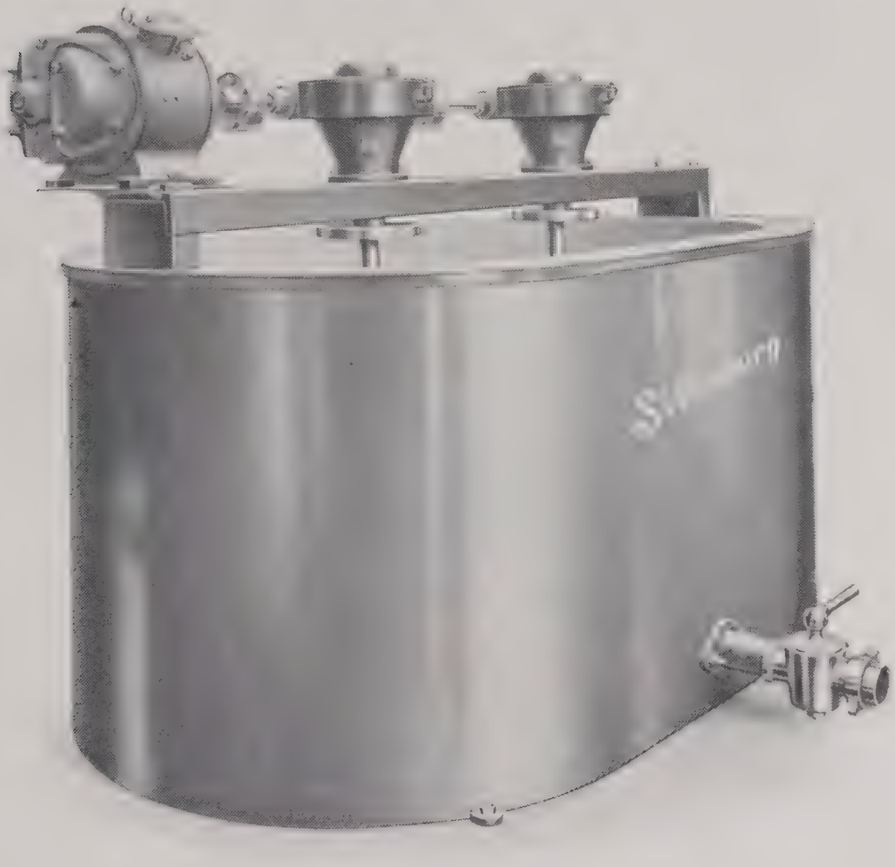


Fig. 10. Melting tank with stirrers (Courtesy: *Silkeborg Engineering Works*).

have rounded ends and double agitators of the gate pattern type: they have capacities of 2–5 tons.

According to the lay-out of the factory the liquefied fats and oils run by gravity or are pumped to the Composition Tank where they are weighed out in the required proportions. This tank should be placed in a warm room to prevent crystallization of high-melting constituents, as the individual fats and oils are stored at temperatures only slightly above melting point. Fat-soluble ingredients such as colouring matter, vitamin concentrates etc. (see later) are generally added at this stage and carefully weighed out before addition as they are only used in very small proportions, less than 0·5 per cent.

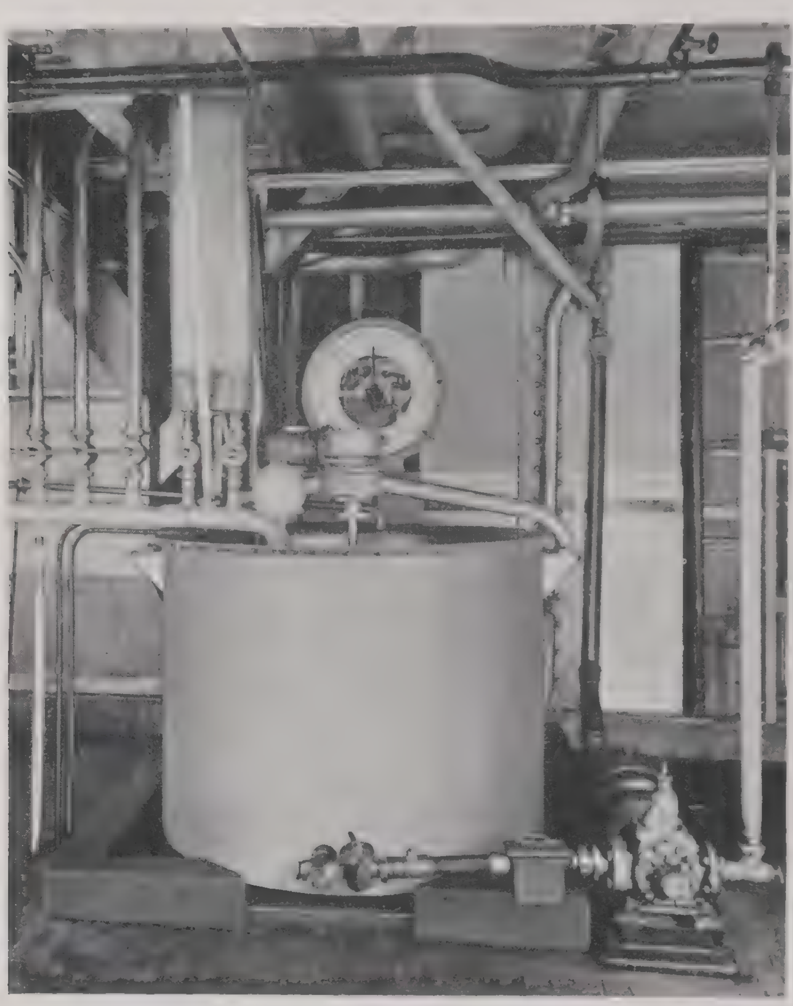


Fig. 11. Composition weighing tank (Courtesy: *A. Johnson (London) Ltd.*).

Fig. 11 illustrates a Composition Weighing Tank with five pipe and valve connections to storage tanks; two of the pipes are lagged for conveyance of high-melting fats. The pipes discharge into a common header and through this into the weighing-tank. This is emptied via a flexible pipe connection and a rotary pump.

Fig. 12 shows a view of a room with Composition Tanks.

From the Composition Tank the blend is pumped or run by gravity to Tempering Tanks, cylindrical or rectangular tanks of tinned or stainless steel or of aluminium, provided with stirrer and hot water jacket or coils for heating or cooling. As the various fats and oils are stored at different temperatures the fat-blend must be adjusted in the Tempering Tanks to the correct temperature for the next step, the emulsification or churning process. This temperature depends on the blend and the emulsification technique, etc., and may vary from about 26°C to 40°C or even higher in the case of some confectionery margarines. Where emulsification is done in batch churns one tempering vessel should suffice for each churn, as it can be refilled and adjusted while the churning process is being completed and the churn emptied. Where the emulsification process is continuous two or more tempering vessels are needed for each emulsifier to ensure uninterrupted supplies at the right temperature. Fig. 13 shows a typical tempering vessel with jacket for heating or cooling and with motor-driven agitator.

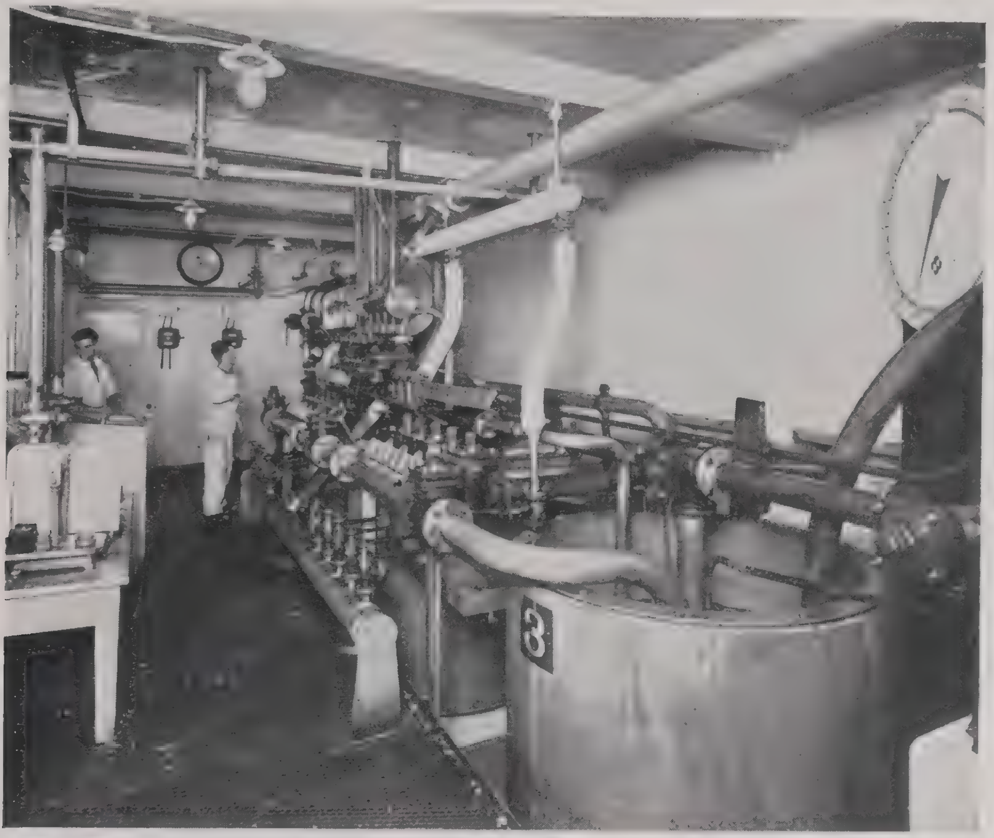


Fig. 12. Room with composition tanks (Courtesy: "*Food*" and *Van den Berghs and Jurgens Ltd.*).

In planning storage, melting and composition lay-outs, arrangement of pipes should be such that they drain completely and there are no bends or pockets where fat may lodge and solidify; where pipes have to convey high-melting fats it is advisable to jacket them or run a small steam pipe alongside; asbestos bands with electrical heating wound spirally round the pipes are also sometimes used.

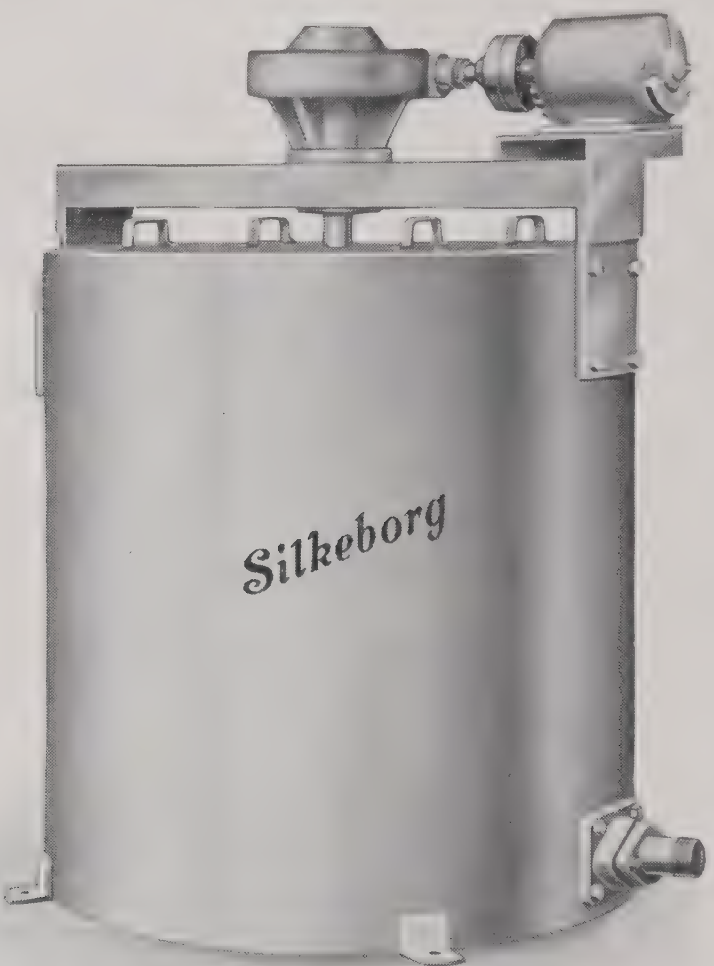


Fig. 13. Tempering tank (Courtesy: *Silkeborg Engineering Works*).

Milk and Other Aqueous Ingredients

When margarine was first made, a very large proportion, 50–60 per cent, of equal parts of milk and water was used for emulsification with the margarine fat to give a product similar to butter in flavour and culinary character. Much of the moisture was worked out again in the kneading process to get the final moisture percentage below, usually, 16 which is now the statutory upper limit in most countries. Improved technique of milk treatment has made it possible for manufacturers to obtain equally good or better results with much smaller proportions of milk than in the early days of the industry, and proportions as low as 5–7 per cent are now possible with well ripened milk; the balance of the final moisture content is then made up by addition of water to the milk before or during the emulsification process.

The purpose of using milk is threefold: It can be used for imparting the desirable flavour and aroma and eliminating the fat-taste of margarine; it aids in the production and stabilization of the emulsion, and it provides some of the solid non-fatty ingredients which give the characteristic brown granular aromatic sediment, as does butter, when used for frying.

The milk-phase has been used in the form of cream, whole milk, separated or skim milk or re-dissolved milk powder. Whey, the milk serum from cheese making, and buttermilk from butter making are also used at times.

In some countries statutory regulations prohibit the use of milk or milk derivatives in margarine, and water has to be used as the aqueous phase. The same is the case in some countries when unsalted margarine is made, as this might deteriorate prematurely if milk solids were present, or where for ritual or dietetic reasons the use of milk is excluded. Flavouring ingredients of various kinds are then employed if an absolutely bland flavour is not wanted. Emulsion stabilizers are then also often used as well as various ingredients to give the brown sediments when frying.

In most cases, however, milk is the basis of the aqueous phase in good margarine, and the early development of the margarine industry was mostly in regions of highly developed milk production. It is principally used in the form of separated or skim milk or, in recent years, as dissolved skim milk powder. The aqueous liquid separated from margarine on melting is generally called margarine serum.

1. MILK AND MILK DERIVATIVES

Cost considerations as well as statutory limitation on the percentage of butterfat permitted in margarine have practically eliminated the use of cream as a source of the aqueous phase. If it were used of the concentration of average cream for butter-making, *ca.* 30 per cent, it would give the margarine a butterfat content of 6–8 per cent, which would be legal in some countries where the maximum allowed is 10 per cent, but some countries have limits of 3 per cent and in many no butterfat is permitted. From the point of view of obtaining in the margarine a fine butter aroma and as an aid to good consistency cream is a valuable constituent, but it is often found that the keeping quality of the margarine suffers, owing to the greater susceptibility of butterfat to attack by micro-organisms with the resulting hydrolysis of the low-molecular glycerides and development of rancid flavour. The unfavourable opinion about the addition of butterfat derives probably from times and places when there was insufficient bacteriological control of the cream supply, or where the butterfat was incorporated in the form of purchased butter. From the aroma aspect cream has advantages, as will be referred to later under "ripening", when properly controlled, but as stated cost considerations, apart from statutory ones, now exclude its use.

Whole milk has been used much more than cream, but there is little advantage in practice in its use compared with skim milk. When used as the aqueous phase it introduces 0·5–0·7 per cent butterfat in the margarine and this is more than permitted in some countries. It is, when properly ripened, a better source of aroma than skim milk, but difficulties with keeping quality of margarine may arise, as mentioned under cream. The cost is also in many places too high for any potential advantages.

The aqueous phase is therefore predominantly skim milk which from modern centrifugal separators contains less than 0·1 per cent fat. In some countries and districts where a supply of fresh skim milk is difficult to obtain, skim milk powder is used in its place. This should be of the spray-dried type because of its better solubility and flavour than the roller-dried variety and because the lower temperature at which it has been dried makes it better for the ripening process.

Some manufacturers believe that the keeping quality of margarine is improved by reducing its protein content derived from the milk and thus lessen the nutrients for bacterial growth, particularly for the proteolytic organisms. They therefore use the whey from milk or skim milk after rennet precipitation of the casein curd. The filtered or strained whey is still suitable for development of lactic acid bacteria in the souring process although the flavour of the ripened liquid is rather different and less aromatic. If a sweet unsoured serum is preferred the whey can be used after pasteurization. There is, however, the risk with whey that enzymes from the rennet may interfere with the flavour, and this system of preparing the aqueous phase is not much used now. It has also been found that in certain circumstances the casein of the milk can exercise a preserving effect on the margarine fat as a source of antioxidants.

Control and Pasteurization.—With a perishable substance like skim milk it is essential that it should be available to the margarine manufacturer in fresh condition. At one time it was, even in small margarine works, customary to receive the milk as whole milk direct from farms or collecting stations. This is undoubtedly the best system, as it enables the manufacturer to check and select the quality. The milk was then merely strained and cooled at the place of origin and dispatched once or twice a day to the factory dairy where, after tests for acidity and fat-content and in smaller factories flavour tests, in larger quality tests such as the methylene-blue test or the combined methylene-blue reductase fermentation test [106], the milk was separated and pasteurized. The cream was sometimes disposed of as such or used in margarine; sometimes it was made into butter. In those days some of the largest and most progressive dairies were attached to margarine works. Where whey was used for margarine, cheese manufacture or manufacture of casein were subsidiary industries. The changed pattern of the milk industry, economic considerations or in many places control regulations for milk distribution have resulted in margarine manufacturers drawing their supplies of liquid milk in the form of skim milk usually from collecting stations or butter factories, where fresh milk is received daily from farms. As a measure of precaution the separated milk is in many cases pasteurized and cooled to 5–6°C before dispatch to the margarine works, but where it has to travel only a moderate distance cooling down to 2–3°C is preferred by some manufacturers who wish to have the heat treatment of the skim milk under complete control.

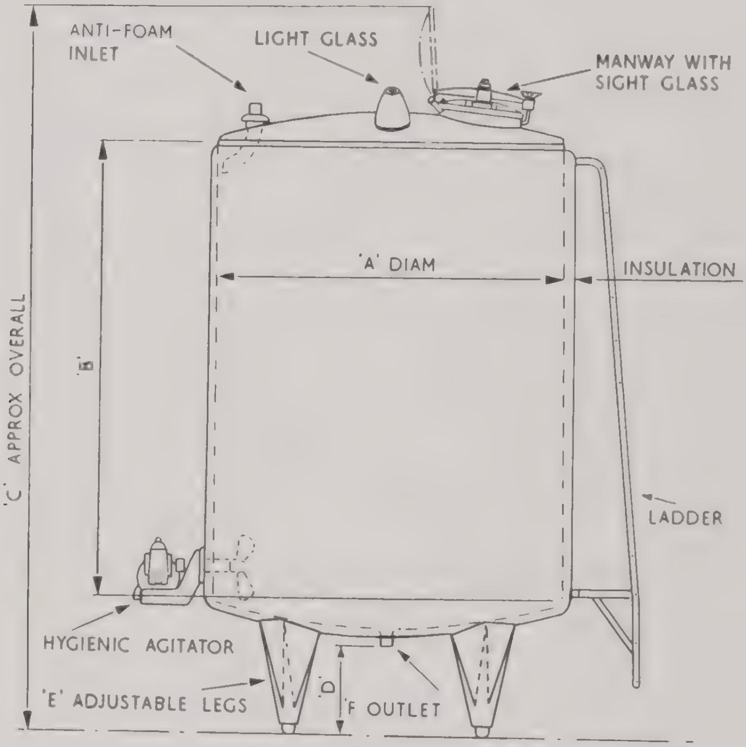
On arrival the milk, whether pasteurized or merely cooled, is tested for quality. It should be free from cooked or other foreign taste and show the normal low acidity of fresh milk. The method of expressing acidity is not standardized; some factories use pH determination, fresh milk has a pH of *ca.* 6·6, but titration with alkali is more usual. The result is frequently expressed in degrees Soxhlet-Henkel (S/H), which is the number of ml of 0·25 N. alkali required to neutralize 100 ml milk, using phenolphtalein as indicator; fresh milk shows 6·5–8 degrees S/H. Other manufacturers titrate 50 ml with 0·1 N.alkali, others 20 ml or 100 ml with 0·1 N. alkali. If 20 ml are used for titration against 0·1 N. alkali, fresh milk and skim milk should show an acidity of 3·5–4 ml. This acidity is natural and due to caseinate, citric acid and acid phosphates in the milk; if it is significantly below it may indicate admixture of milk from diseased cows; if higher, it may indicate incipient development of acid-producing bacteria. A chemical and biological quality test, which is frequently used in margarine dairies, is the combined methylene-blue reductase and fermentation test [107], as the time taken for decoloration of methylene-blue by the reductase enzyme of the bacteria is a measure of the number of bacteria present, and the type of curd formed in the fermentation test is an indication of the type of organisms. Fresh unpasteurized whole milk ought to show not less than five hours for decolorizing and a good even gelatinous curd; pasteurized skim milk should show seven hours or more for decolorizing, but the curd is often uneven owing to the low number of acid-forming bacteria. The Resazurin test, which is of more recent date, is now used in some cases on whole milk and is considered more searching for reducing-systems in milk due to a variety of causes, but as a measure of bacterial content methylene-blue is the superior indicator and is particularly informative when combined with the fermentation test.

Small factories receiving whole milk often use the simple alcohol test for checking the quality. When 5 ml milk is mixed and shaken with 5 ml 70 per cent alcohol it should show no sign of coagulation; if the acidity is higher than what corresponds to 8–9 degrees S/H it coagulates in the alcohol test and would not stand up to flash pasteurization without clotting.

Actual bacterial counts by direct microscopic examination or by counting colonies developed on solid media are not practical methods for works control, but are used in factories with bacteriological laboratories for checking occasionally the mentioned methods or for research purposes.

In order to maintain regular conditions for the ripening process milk cannot always be taken into use immediately on arrival and it may therefore by advisable to pasteurize it on receipt. The "holding" process, where milk is kept at 63 C for 30 minutes is not as suitable for skim milk as the short time-high temperature process, 15 seconds at 72°C, or the flash-pasteurization method at 82–85°C. Milk required at once can then be cooled to ripening temperature, 18–26°C, but if not immediately required it should be stored at less than 5°C until wanted. If skim milk received from outside has been satisfactorily pasteurized and arrives with a temperature below 8°C some take it into cold storage direct and repasteurize immediately before use.

Storage tanks for skim milk should be of the recognized type for milk

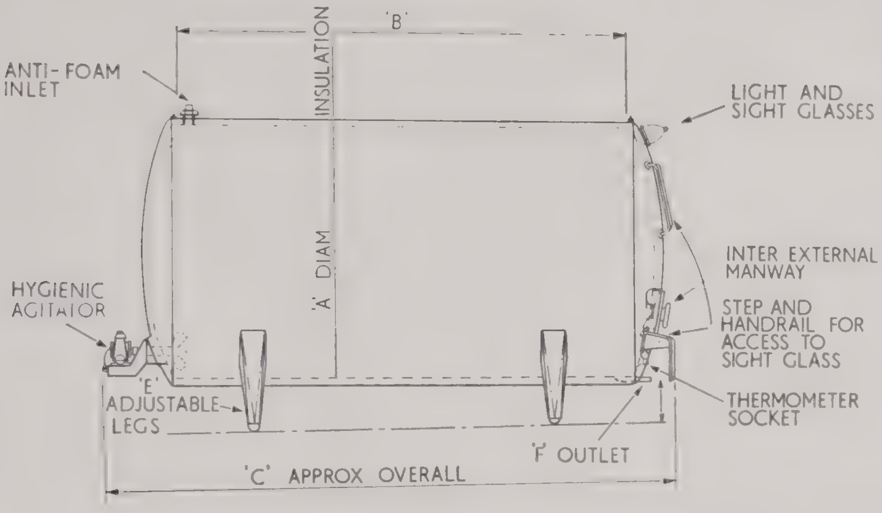

ANTI-FOAM INLET
LIGHT GLASS
MANWAY WITH SIGHT GLASS
'A' DIAM
INSULATION
'C' APPROX OVERALL
'B'
LADDER
HYGIENIC AGITATOR
'E' ADJUSTABLE LEGS
'D'
'F OUTLET

Capacity Gallons	A	B	C	D	E	F
500	3′ 9″	7′ 3″	9′ 9″	1′ 3″	4	2″
750	5′ 0″	6′ 0″	8′ 9″	1′ 3″	4	2″
1000	5′ 6″	8′ 0″	10′ 9″	1′ 3″	4	2
1500	5′ 6″	10′ 0″	13′ 0″	1′ 3″	4	2″
3000	7′ 0″	12′ 0″	15′ 0″	1′ 3″	6	3″

Fig. 14. Vertical storage vessel for milk
(Courtesy: *A. Johnson (London) Ltd.*).

storage and made of aluminium, stainless steel or glass-enamelled steel; they should be easy to clean and means for steam sterilization should be provided. It is better to place them in a room kept at the low storage temperature than to have cooling coils inside. Alternatively they may be jacketed.

Fig. 14 shows a milk storage vessel of the vertical cylindrical type, constructed in stainless steel. By letting the inlet pipe deliver the milk against the side foaming is reduced. The tank is closed and has a manhole and sight glass on top. If placed in a cold storage room insulation is unnecessary, and when used for storage of skim milk the agitator is superfluous. For a 2000 gal. capacity the diameter is 6 ft. 3 in., the cylindrical height 10 ft. Fig 15 shows a similar tank, but arranged as a horizontal cylinder, which for 2000 gal. capacity has a diameter of 7 ft. and length 8 ft. These tanks are standing well off the floor, about 1 ft. 6 in., for the sake of cleanliness.


ANTI-FOAM INLET
INSULATION
'B'
LIGHT AND SIGHT GLASSES
'A' DIAM
INTER EXTERNAL MANWAY
HYGIENIC AGITATOR
STEP AND HANDRAIL FOR ACCESS TO SIGHT GLASS
'E' ADJUSTABLE LEGS
THERMOMETER SOCKET
'F' OUTLET
'C' APPROX OVERALL

Capacity Gallons	A	B	C	D	E	F
500	4′ 1″	6′ 0″	10′ 4″	1′ 3″	4	2
750	5′ 0″	6′ 0″	10′ 6″	1″ 3″	4	2
1000	5′ 8½″	6′ 0″	10′ 9″	1′ 6″	4	2
1500	6′ 3″	8′ 0″	12′ 2″	1′ 6″	4	3
3000	7′ 0″	12′ 0″	16′ 9″	1′ 6″	6	3

Fig. 15. Horizontal storage vessel for milk
(Courtesy: *A. Johnson* (*London*) *Ltd.*).

Plant for pasteurizing skim milk is of the well known types used for consumer milk and in creameries. As an example of the flash-pasteurizer of the older type which is still used in many factories of small or moderate size, Fig. 16 shows a drawing of a Silkeborg vertical type with bottom drive by belt and bevel-gear transmission running in oil bath. The pasteurizer is placed on a cast iron base (*1*) and consists of an inner container (*3*) with paraboloid heating surface, on the top of which is the cover (*4*) with outlet (*8*) for pasteurized milk. The cover is held by loose clamps and sealed by an easily removable loose rubber ring. In the inner container is fitted an agitator (*5*) shaped to the surface of this and provided with three or four blades, which, when the agitator rotates, spread the milk, entering at the bottom through pipe (*6*), in a thin layer over the heating surface. The agitator blades are carried by arms (*11*) from the central shaft (*12*) which is driven from the bevel gears via a square-coupling. The shaft does not pass through the bottom via a stuffing-box, but through an open pipe (*13*). The paraboloid inner container is surrounded by a steam jacket (*2*) with insulation casing, steam inlet (*9*), condensate overflow (*10*) and safety valve (*7*). A thermometer (*14*) shows the temperature of the pasteurized milk at the outlet.

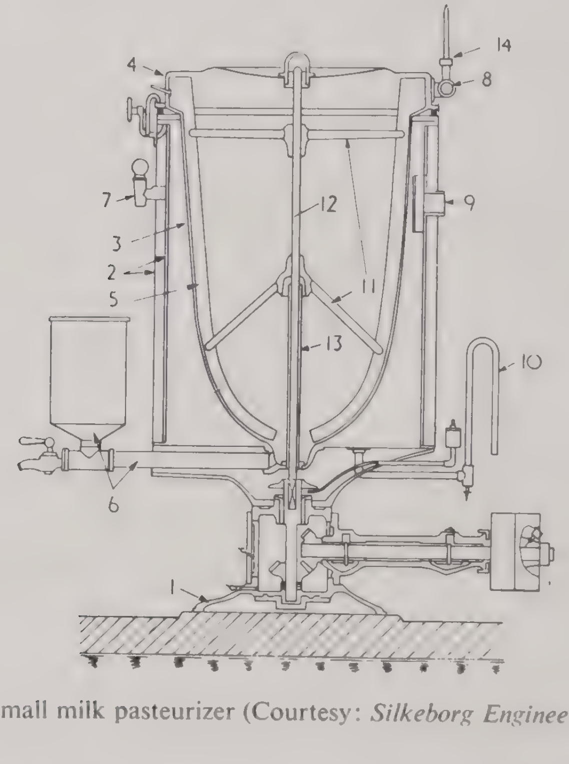


Fig. 16. Small milk pasteurizer (Courtesy: *Silkeborg Engineering Works*).

The cold milk enters the pasteurizer by way of the regulator funnel and supply pipe (*6*) at the bottom where the rapidly revolving agitator flings it against the heating surface, and under the increasing centrifugal force of the agitator and the paraboloid shape of the surface it climbs as a film under increasing temperature towards the top and leaves by the tangentially fitted outlet (*8*), the force being sufficient to lift the pasteurized milk several feet.

A pasteurizer to heat 1,000 litres skim milk per hour from 5 C to 90 C requires a heating surface of 1 m^2. This type of plant is made with heating surface from 0·3 to 2·4 m^2. While the inner container, agitator and other parts which come in contact with the milk were formerly made of tinned copper and tinned brass, stainless steel is mostly used and this facilitates cleaning with detergents and chemicals. To prevent the deposition of milk stone in the hot zone it is advisable to run a little water through the plant before the milk and also rinse with water immediately following the milk.

Other types have the driving gear at the top, carried on brackets, or the whole pasteurizer may be suspended in a strong frame which carries the driving gear at the top and the pasteurizer on two bearings at the side which permit it to be tipped over for easier cleaning after disconnecting the agitator.

As the milk after pasteurization is cooled down either to storage or to ripening temperature, larger installations combine usually for the sake of heat economy the pasteurizer with a heat exchanger or regenerator, a separate unit in which the pasteurized milk preheats the untreated milk on the way to the pasteurizer while itself being cooled down, the final cooling being done by water or refrigerated brine. In modern works pasteurizing and heat exchange are in one plant, the plate-pasteurizer. As these are built in a wide range of capacities, are thermally highly efficient and, because of their compactness, take up relatively little space they are gradually replacing the older types of pasteurizers.

The plate-pasteurizer, as the name indicates, consists of a number of stainless steel plates, fitted parallel in vertical position and suspended on a carrier bar from or between supporting panels. The plates which have been stamped out to give a surface with a number of grooves or corrugations, see Fig. 19, can be pressed close together by means of a spindle actuated by handwheels or by a ratched tightening handle, the distance between the plates being determined by grooved ledges on the plates into which packing ropes and gaskets of rubber compositions or other suitable material fit and ensure tightness of the chambers between the plates when they are clamped together. The plates have inlet and outlet ports for the two liquids between which heat exchange takes place, and the gaskets round these ports are arranged in such a manner that a liquid has access to and outlet from every alternate chamber space. The groove pattern on the plates helps to create a turbulence in the flow across the plates, promotes heat transfer and ensures equal heating of all milk particles; in the thin turbulent film which is surrounded by a medium of different temperature in adjacent chambers on each side, heat transfer is rapid and uniform and the thermal efficiency of the plant is therefore high. The circulation of the different liquids is effected by stainless steel pumps of sanitary construction. In some plants and for special purposes the final heating can be arranged for steam. The system is completely closed, and for this reason, and because the thin film permits rapid heating, and contact is entirely with stainless steel, the milk preserves its original good flavour, even after high pasteurization temperatures. The closed system permits also easy cleaning as after use the apparatus is simply washed out with water, detergents, dilute nitric acid and other sterilizing solutions. From time to time the plant is dismantled for inspection for scale formation or damage to gaskets, but the simple construction makes this an easy task.

The operating principle is explained in Fig. 17 which shows a flow diagram of an A.P.V. plate pasteurizer designed for working on the high-temperature-short-time system where milk should be held 15 seconds at 72°C (162°F); it therefore includes a Holder-tube for hot milk and an automatic flow-diversion valve for returning milk to the feed tank if the temperature should fall below that required. As shown, the feed pump draws the raw milk from the balance or feed tank which is connected to the raw milk supply. The incoming milk is then pumped in controlled flow through the Regeneration section where it is pre-heated by the milk, which comes at pasteurization temperature from the Holder-tube on the way to the Cooling section. After the heat exchange in the Regeneration section the pre-heated milk passes through a filter, built into the apparatus in duplicate, to the Heating or Pasteurization section where it is brought up to pasteurizing temperature by means of hot water, which is heated to an appropriate temperature in a separate tank by steam injection and circulated by a separate hot water pump. The pasteurized milk then passes to the Holder-tube, which is built into a panel, where are placed all controls for starting and stopping the motors, for recording the temperatures at the different stages and for operating the compressed-air flow-diversion valve. The Holder-tube is dimensioned to ensure that the pasteurized milk is held at pasteurization temperature for the required period. After passing the flow-diversion valve the hot milk flows on its way out through the Regeneration section, giving off 70–85 per cent of its heat to the incoming milk by passing through the alternate chambers, and on to a Cooling section, where cold water is used for cooling. Finally it can be passed through a Chilling section to be further cooled with ice-water, if required. Cold water and chilled water have their separate circulation systems.

An illustration of the set-up of a plant operating according to the system shown in the flow-diagram is given in Fig. 18, and of an individual plate with its design of grooves for even distribution and maximum heat transfer in Fig. 19. (*5*) is the specially shaped hanging-eye ensuring accurate alignment and easy removal, (*2*) and (*2A*) are ports for one liquid, (*4*) and (*4A*) for the other, which from the arrangement of the packing rings has access to the surface shown. (*3*) is the gasket of special section and material, moulded in one piece and firmly attached to the plate, but easy to replace.

There are several makes of plate pasteurizers, differing in details such as design of grooves and ridges on the plate, suspension and assembling system, pipe connections, etc., but operating on the same principle. Steam is sometimes used as the final heating medium instead of hot water. Where high-temperature pasteurization, 80°C and above, is used a holding arrangement is unnecessary. In some plants the holding chamber is provided in the plate section. The capacity of a plant can be varied considerably by fitting a larger

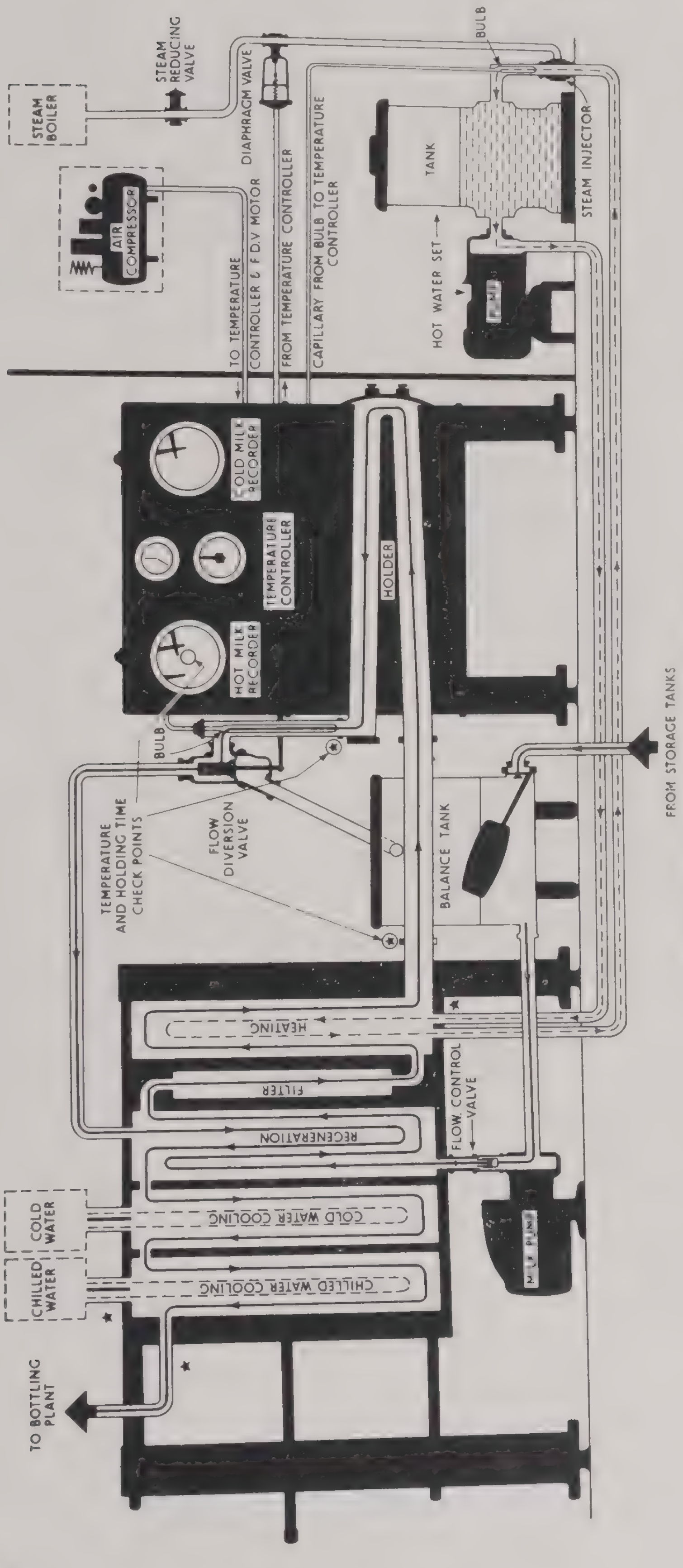

STEAM BOILER
STEAM REDUCING VALVE
AIR COMPRESSOR
DIAPHRAGM VALVE
BULB
TANK
STEAM INJECTOR
HOT WATER SET
PUMP
TO TEMPERATURE CONTROLLER & F.D.V MOTOR
FROM TEMPERATURE CONTROLLER
CAPILLARY FROM BULB TO TEMPERATURE CONTROLLER
COLD MILK RECORDER
TEMPERATURE CONTROLLER
HOT MILK RECORDER
HOLDER
BULB
TEMPERATURE AND HOLDING TIME CHECK POINTS
FLOW DIVERSION VALVE
BALANCE TANK
FROM STORAGE TANKS
HEATING
FILTER
REGENERATION
FLOW CONTROL VALVE
COLD WATER COOLING
CHILLED WATER COOLING
COLD WATER
CHILLED WATER
MILK PUMP
TO BOTTLING PLANT

Fig. 17. Plate pasteurizer, flow diagram
(Courtesy: *A.P.V. Co. Ltd.*).

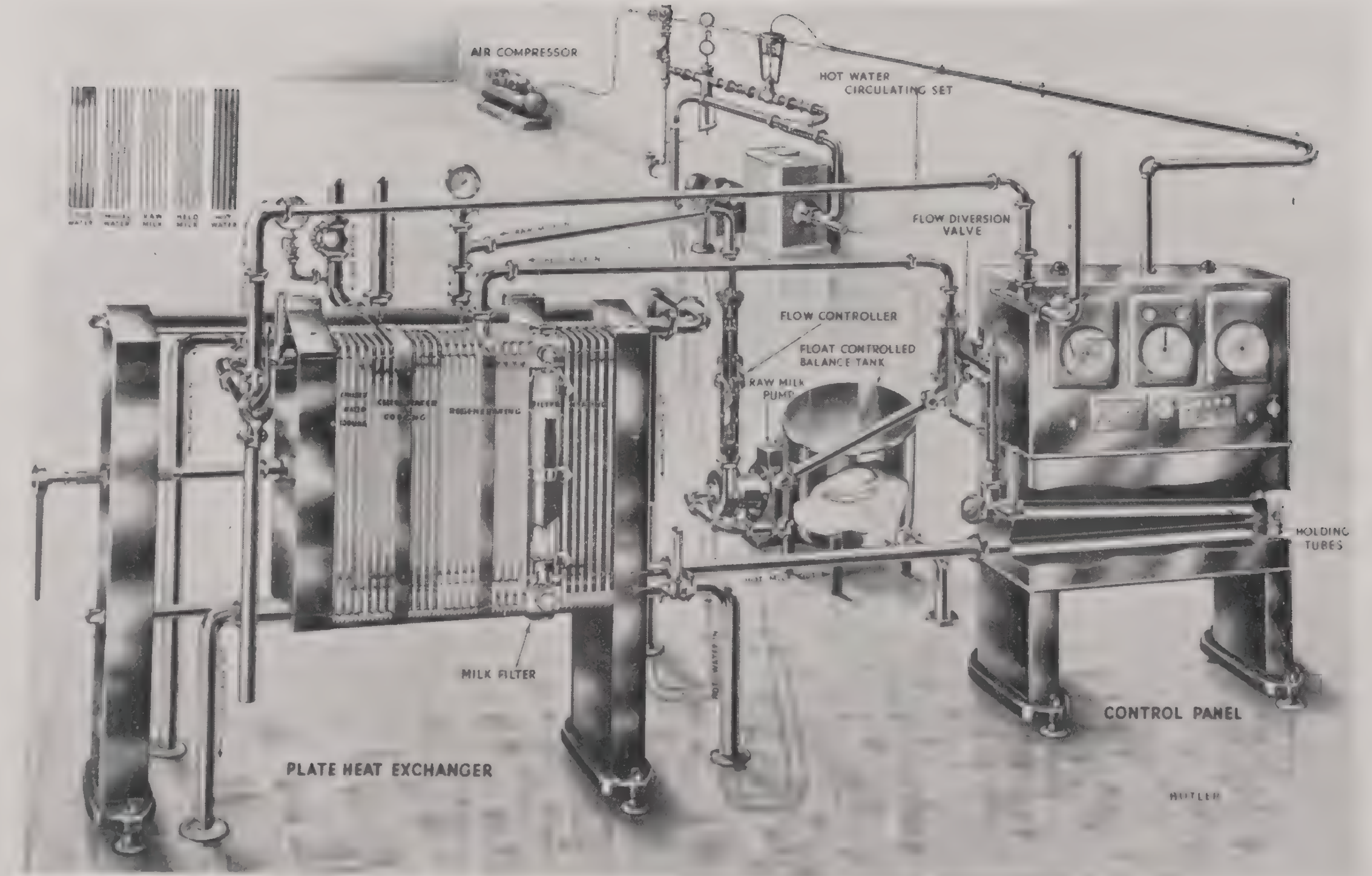

AIR COMPRESSOR
HOT WATER CIRCULATING SET
FLOW DIVERSION VALVE
FLOW CONTROLLER
FLOAT CONTROLLED BALANCE TANK
RAW MILK PUMP
HOLDING TUBES
CONTROL PANEL
MILK FILTER
PLATE HEAT EXCHANGER
RAW MILK
HELD MILK
HOT WATER
REGENERATING
HOT WATER

Fig. 18. Short-time plate pasteurizer
(Courtesy: *A.P.V.* Co. Ltd.).

or smaller number of plates in each section as needed, and as sizes are made for capacities from 200–300 litres (50–70 gal.) per hour to 10,000 litres or more this modern type of pasteurizer is suitable for factories of all sizes. Because the stainless steel construction permits easy cleaning without dismantling after use, little labour is used for this operation and the plant can be economically used for short or for protracted runs.

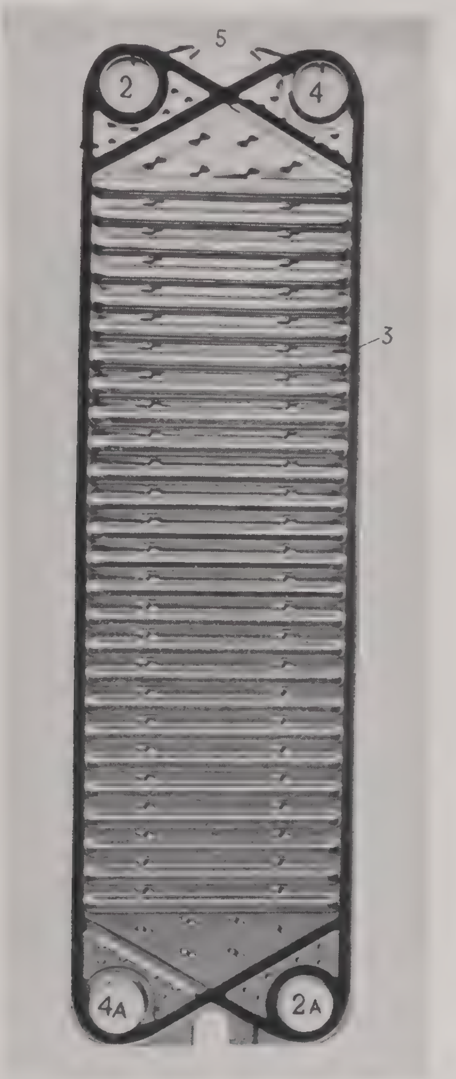


Fig. 19. Plate for pasteurizer (Courtesy: *A.P.V. Co. Ltd.*).

Other pasteurizers combining heat exchange and pasteurizing in one unit are available in various constructions. An important point to consider in deciding preference is the ease of cleaning, which is a more essential question in margarine dairies than small differences in thermal efficiency.

The flash pasteurizers, plate pasteurizers and the various types combining pasteurization and heat exchange are constructed for continuous throughflow of the milk. A simple type of batch pasteurizer for limited quantities is the vat pasteurizer, a cylindrical or rectangular tank, either jacketed or surrounded by a close-fitting coil through which hot water circulates for heating and cold water for cooling; a propeller agitator maintains lively circulation in the milk during heating and cooling. Fig. 20. The temperatures and period of heating can be varied to suit circumstances. Another popular type of vat pasteurizer is the revolving coil vat, a horizontal oblong insulated vat with semi-cylindrical bottom: a rotatable helical coil which, when the vat is full, is submerged in the milk serves as agitator and coil for heating and cooling. This kind of vat is not as easy to clean as the plain jacketed vat with propeller. Both have the advantage that they can also be used as ripening vats, and where the quantities of milk to be dealt with are such that they can be placed in these vats directly on arrival, much pumping

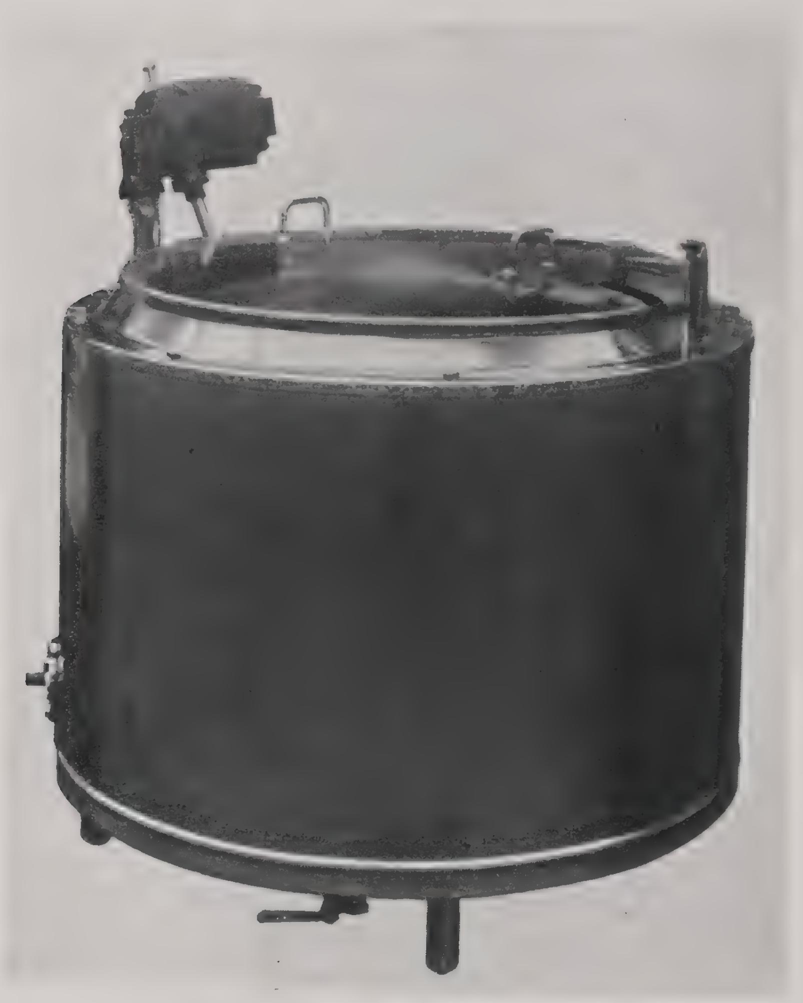


Fig. 20. Cylindrical batch pasteurizer
(Courtesy: *A.P.V.* Co. Ltd.).

about for pasteurization, storage and ripening is saved and infection risks avoided.

Pasteurization, even at temperatures close to the boiling point, does not eliminate all micro-organisms; some thermoduric bacteria and spores of some spore-formers may survive, but pathogenic bacteria are killed off. The number surviving pasteurization from good quality milk is however very small and of no practical importance where milk for margarine is used for the conventional process of ripening. Where milk is used for a continuous ripening process or where milk for ripening is seeded or inoculated with a percentage of a previously ripened batch it is important to have the supply sterile, or very nearly so, and it must therefore be heated under pressure and exclusion of air to temperatures of 118–121°C, when heat resisting organisms and spores are almost completely destroyed and the milk may be considered sterile for practical purposes. With those methods of ripening there might otherwise be an accumulation of undesirable organisms in the ripening tanks and the ripening process be thrown out of balance. Various high-pressure tubular heaters are available for this treatment; in these the milk travels in a thin film through the narrow annular spaces of concentric tubes, between surfaces heated by steam. From the heater the milk passes to a pressure cooler of similar construction with water and brine for cooling it down to the temperature of ripening. In spite of the high speed and the short time the milk film is exposed to the heat there is a tendency for a deposit of milk solids to form on the surfaces where the temperature is highest—the end of the heating and the beginning of the cooling section—resulting in irregular flow and scorching, and frequent cleaning of the tubular surfaces is necessary, and cumbersome.

A slightly different construction is adopted in the Silkeborg tubular sterilizer. Fig. 21. Steam is used in the heating jacket surrounding the milk pipes. These together with other parts in direct contact with milk are made of stainless steel, which permits the use of acids and chemicals for cleaning. This sterilizer is used in conjunction with a plate heat-exchanger for heating raw milk by the outgoing sterilized milk and for further cooling of the latter by cold water to the storage or processing temperature. The end covers of the tubular sections are easily removable for inspection.

Better results are claimed with a plate sterilizer of similar construction to plate pasteurizers, made of stainless steel and with packings to stand the pressure and conditions for working to sterilization temperatures of 120–122°C. There is the usual heat-exchange section, and superheated water of 125°C from a separate small water heater is used for the high-temperature section and circulated by pump in a closed system. Water is used for cooling to ripening temperature, brine for cooling for storage. It is important that the layers of milk are very thin and that the temperature difference between the heating medium and skim milk does not exceed 5°C. Under those conditions sterilization is achieved without scorching and deposit, and the system can easily be cleaned and pre-sterilized with a solution of caustic soda followed by a solution of 1 per cent nitric acid, and boiling water for rinsing. At times skim milk sterilized in this manner has a slight taste of heated milk, but this is not discernible after ripening.

As mentioned, there are numerous makes of pasteurizers varying in some details from those described which indicate the main types. In margarine factories they are principally used for skim milk, where regulations applicable to consumer milk and questions of "cream line" do not have to be considered. For margarine manufacturers the important points are, that in addition to generally good pasteurization effect those organisms which particularly endanger the keeping quality of margarine, i.e., yeasts, moulds and fat-splitting organisms, are destroyed; that organisms which might interfere with the right development of culture organisms added for ripening are killed or thoroughly weakened; that the milk after pasteurization and cooling possesses no taste that might give an undesirable flavour to the ripened milk or the margarine; and that the pasteurizer is reliable in operation, thermally economical and easy to clean.

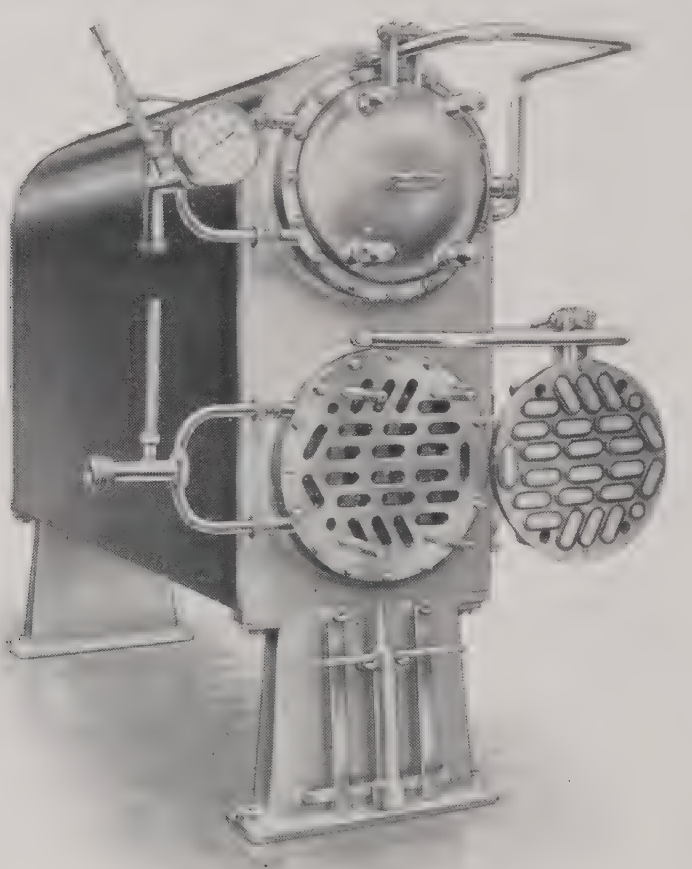


Fig. 21. Milk sterilizer (Courtesy: *Silkeborg Engineering Works*).

Skim milk powder for margarine should be of the spray-dried variety because of its greater solubility, practically 100 per cent. It is tested for flavour quality both as dry powder and when dissolved to the concentration of reconstituted skim milk, usually one part powder to 9–10 parts water by weight. The powder should be free from stale or rancid odour and should be free-flowing and dry, i.e., less than 5 per cent moisture; it should dissolve easily to a 10 per cent solution and only show traces of sediment; the solution, when tested for acidity, should be similar to fresh skim milk as shown for example by titration by the Soxhlet-Henkel method, which should give an acidity of 6–8 degrees. Its content of bacteria should be low and in the methylene-blue reductase test it should keep more than 7 hours; the test for coliform organisms should be negative. When dissolving it in water—not warmer than lukewarm—it is poured through a strainer into a stainless steel tank, where the water is kept in lively motion by a paddle or propeller agitator. When all the powder has been added and dissolved the solution is pumped through a fine-meshed sieve before being stored. spite of the low bacterial count of good skim milk powder it is advisable to pasteurize the solution before use. This is often done by warming the solution in the dissolving tank, after all the powder has been dissolved, and keep it at 65 C for 30 minutes, but it can also be done, after sieving, by the other recognized pasteurization systems and plants. If the solution is stored before use it must of course be cooled below 5–6°C.

The milk, whether as the original skim milk or as reconstituted milk, is practically always used in the "ripened" or "soured" form after seeding or inoculation with cultures of selected strains of lactic acid forming bacteria. To use unsoured or sweet milk in the margarine entails a considerable risk, as this highly perishable material would provide organisms, which survive pasteurization or might adventitiously get into the margarine from the air, the plant or from other materials during processing, with an excellent medium for growth and developments, leading to undesirable flavour, rancidity and premature deterioration. Milk ripened by means of the proper lactic acid organisms presents an unfavourable medium for development of many, for the preservation of margarine, harmful micro-organisms, and it provides the means of imparting to the margarine the important taste and aroma similar to that of butter.

2. MILK RIPENING AND AROMA DEVELOPMENT

Theory.—In developing methods for preparing milk for use in margarine the industry benefited from those advances which took place in the chemical and bacteriological science of dairying in connection with improvements in the preparation of cream for butter making. The original system on farms of collecting cream from several days, partly to save the labour of churning butter daily, partly to have larger quantities available, led to the cream usually being sour when churned, because of infection with the lactic acid bacteria always present on farms. It was found that not only gave sour cream a higher yield of butter, but if the souring process was right, the butter had a definite and pleasant aroma, not obtainable when sweet cream was used for churning, and it also kept better. There was, however, a good deal of uncertainty in this method of spontaneous souring, and often undesirable organisms predominated and gave a poor quality of cream. This was usually avoided by seeding the first collected cream with some buttermilk from a previous successful batch and thus developing in the cream, and in any later added, the right kind of organisms. Bacteriologists soon found that certain types of lactic acid producing bacteria were required for good results and about 1890 STORCH in Denmark and WEIGMANN in Germany introduced the use of special cultures of these as seeding material, or starters, in cream to give a uniform good quality of butter. The organism responsible was generally termed *streptococcus lactis*. The successful use of pure cultures was greatly aided by the introduction of pasteurization of the milk or cream in order to eliminate the other micro-organisms already present in the raw milk and thus give the culture organisms a free field for development.

The margarine industry soon adopted the same system for its treatment of milk and used the same kind of cultures for inoculating the pasteurized skim milk. The process was usually referred to as "souring" of milk, as the the most important biochemical process was thought to be the conversion of lactose into lactic acid with the production of minor amounts of carbon dioxide, acetic acid and some aroma bodies.

Further studies of the bacteriology and biochemistry of the process led about 30 years later to the publications in Europe and in U.S.A. of reports of work which showed that more than one type of organism was responsible for the result [108] [109] [110]. In addition to the *Streptococcus lactis*, of which the variety particularly suitable for cream ripening was called *Str. cremoris* by ORLA-JENSEN [111] two or more other organisms were present; *Str. cremoris*, like *Str. lactis*, was principally responsible for the production of lactic acid, whereas the other organisms, by the Danish bacteriologists called *Betacoccus cremoris*, by HAMMER in U.S.A. called *Str. citrovorus* and *Str. paracitrovorus*, and by many other bacteriologists *Leuconostoc citrovorum*, produced less acid but more aromatic and volatile substances, particularly when growing in symbiosis with *Str. lactis* and *Str. cremoris*. Biochemical studies indicated that the aroma substances, some of which were later identified as diacetyl and acetyl-methylcarbinol, were principally formed by the breakdown, by the aroma bacteria, of lactose and the citric acid in the milk after the *Str. cremoris* had produced a mild acid medium by converting some of the lactose into lactic acid. The process is therefore more than a mere acidulation or souring of the milk and the term "ripening" is more appropriate and is generally used.

Various schemes have been suggested for this breakdown and it appears that methylglyoxal, pyruvic acid and acetaldehyde are intermediary products and carbon dioxide and acetic acid by-products. *Str. lactis* does not ferment citric acid, which in the original milk is present to the extent of 0·1–0·2 per cent.

Of the two acid-producing strains *Str. lactis* seems to favour milk as a medium, *Str. cremoris* cream. Both form strong chains under the optimal conditions of growth ; of the disaccharides they only ferment lactose and they have fair proteolytic properties. This is important as degraded or colloidal casein is an essential nutrient for the aroma bacteria. The optimum temperature for growth varies a little with the medium, whether full milk, skim milk or reconstituted skim milk, but is generally 25–30 C. These organisms will, however, grow quite satisfactorily at the lower temperatures of 20–22° C, which are more favourable for the aroma bacteria, and consequently the lower range is normally favoured in the mixed cultures used for ripening. After a slow initial period of growth after inoculation rapid development takes place between pH 6·3 and 5·3; growth then slows down and ceases at pH 4·6–4·3, when the acid-formers have produced 0·8–1 per cent lactic acid.

The aroma organisms grow in shorter and more slender chains; the various varieties are very similar and differ only on minor points of nutritive requirements and also slightly in the system of citric acid break-down. They produce some lactic acid, but slowly and in small quantities compared with *Str. lactis* and *Str. cremoris*. Their important function is the production of volatile and aroma substances; they grow best at 20–22° C, but the full aromatic flavour is only developed in symbiosis with *Str. lactis* or *Str. cremoris*, which provide first the acid conditions and slight hydrolysis of casein, thereby giving the aroma organisms the best conditions for development and production of aroma, that results from the presence of lactic acid and some volatile acids, such as carbonic, formic, acetic and propionic acids and, in cream, possibly a small trace of butyric acid. Further, diacetyl, acetylmethylcarbinol (acetoin) and butylene glycol are formed and some hitherto unidentified compounds, present in very small traces only, but considered important as giving, with the others, the pleasant mellow flavour, which is generally preferred, but is not fully matched by mixing of appropriate proportions of the identified compounds in pure form.

The results of a test showing the stages in development of acid, diacetyl and acetylmethylcarbinol in skim milk inoculated with 0·2 per cent starter and kept at rather low temperature for slow growth are given in Table XII:

TABLE XII

pH of ripening milk	*ml* 0·1 N. *NaOH pr.* 100 *ml*	CO_2	*Diacetyl p.p.m.*	*A.M.C. p.p.m.*	*Hours held*
5·45	41·9	1·0	0·6	1·3	13·75
5·04	53	1·0	0·7	1·4	15·3
4·84	67	2·0	0·8	1·6	16·3
4·56	74	2·0	0·8	1·9	17·5
4·34	87	4·0	1·2	95	24·5
4·32	91	5·0	1·8	153	28

The acid-producing streptococcus initiates the ripening by forming *d*-lactic acid. When pH is *ca.* 5 growth of these organisms practically ceases and the secondary fermentation begins as shown by increases in CO_2, diacetyl and acetylmethylcarbinol.

It requires great care and observation of many precautions to develop a good culture for ripening, and a procedure must be adopted, which is suitable for the practical conditions to which the process is applied. Separately the different types of organisms will not give the required result as to flavour and aroma; they must be present together in the right proportions at the various stages of development, the acid-producers being more active at the beginning of the ripening, the aroma-producers towards the end, after the ground has been prepared by the acid-producers and a pH of *ca.* 4·9 is reached. It is generally accepted that a good culture should contain a larger proportion of acid-producers, but the records of the proportions vary a good deal. Cultures used for ripening cream and yielding fine aromatic butter have shown 80–90 per cent of the acid-producers. Cultures for milk for margarine should preferably have a higher proportion of aroma-formers, 25–30 per cent, for more intensive diacetyl formation. The quality of the medium, cream or skim milk, is of utmost importance, as the various organisms are extremely sensitive to variations in, or deficiency of, some nutrients. This is particularly the case when reconstituted skim milk is used. Milk is the natural nutritive medium of these organisms, although they thrive in many other nutrients, but milk, particularly processed milk, varies a good deal in the content of some of the quantitatively minor constituents, and some of these are extremely important for the culture organisms. In addition to lactose, casein degradation products and milk salts such as alkali phosphate these bacteria need a number of members of the vitamin B complex, such as riboflavin nicotinic acid amide, pantothenic acid, biotin, folic acid and *p*-aminobenzoic acid. The aroma organisms seem further to require a trace of manganese. Unless these nutrients are present in the milk solution submitted to the ripening process optimal flavour results cannot be expected. Milk powder is more prone to show deficiencies than freshly treated milk or skim milk. Owing to the susceptibility of the bacteria to deficiency in nutrients many attempts have been made to ensure a stronger development by adding certain stimulating nutrients in small quantities to the milk, for example autolyzed yeast, liver extract, hydrolized casein, vitamin B preparations, etc., but the flavour of some of these, as well as their cost, has proved the method to be unpractical so far for industrial purposes. Citric acid which provides the material for the most important aroma compounds and which is usually present in the original milk to the extent of 0·1 0·2 per cent is sometimes added to give a total of 0·3–0·35 per cent.

When in 1929 VAN NIEL, KLUYVER and DERX [112] published the results of their examination of a large number of samples of good butter, and reported that they had found a direct relationship between diacetyl and acetylmethylcarbinol content and aroma, and that the former appeared to be the principal component of the aroma, analyses of the diacetyl and acetylmethylcarbinol content of starter cultures appeared to offer a method of quantitative evaluation of their suitability. Numerous tests of cultures which have given good results both in ripening cream and skim milk have shown a wide variation in diacetyl content; the figures are usually between 3 and 12 mg per litre, but higher figures are not infrequent; the acetylmethylcarbinol content is much higher, about 25 times, but this compound is without odour. When starter cultures are used for ripening cream, the latter when ripe is usually a little lower in diacetyl and carbinol content than the starter. Butter with mild to strong aroma varies from 0·5 to 4 mg diacetyl per kg. Various workers have shown that the diacetyl and acetylmethylcarbinol content of a starter or ripening cream can be increased considerably by aeration during ripening [113] [114]. When this method is applied to cream there are some disadvantages owing to the effect of oxygen on several of the cream constituents and particularly the fat; there is also a loss of some volatile acids, but in ripening skim milk for margarine the process often offers advantages (see page 88).

Another method of assessing the quality of a starter culture is the estimation of the amount of volatile acidic products developed during ripening as shown by titration with decinormal alkali of the distillate with steam from 250 ml of the ripened milk after addition of 15 ml normal sulphuric acid and 5 g sodium sulphate; one litre distillate from the acid producing *Str. lactis* and *Str. cremoris* requires 3–7 ml for neutralization, from the aroma producers 12–18 ml and from good starter cultures 28–40 ml [110]. In ripened skim milk figures of wider variety have been found, evidently due to variations in the starter used and the quality of the milk, but with a standardized process and using the same starter results are fairly constant, and serious deviations in the volatility figures indicate wrong proportions of the organisms responsible for ripening. Usually a test for flavour and aroma by an expert plus a simple titration against alkali, showing that the desired acidity of 36–40 degrees Soxhlet-Henkel has been reached in the expected time at the temperature of ripening, will suffice under practical conditions.

Some other organisms produce in certain circumstances diacetyl and some of the other substances when growing in milk, for example *Str. aromaticus* [115], *Str. citrophilus* [116], *Str. diacetilactis* [117] and some more, but they do not seem to give the accepted mellow flavour and aroma of the older organisms.

Even though the same good starter culture is used the flavour and aroma of a ripened cream for butter making is different from ripened whole milk and from ripened skim milk or reconstituted skim milk. The ripening temperatures are normally different, cream at 15–20 C, skim milk at 18–28°C, but also when ripened at the same temperature the flavours differ. This is probably due to the fat. Cream with 25–35 per cent fat has a more mellow and aromatic flavour than ripened whole milk with 3·5–4 per cent fat and this again shows a difference from fat-free ripened skim milk. Fat is recognized as a strong absorbent of flavours and odours, and the fat in cream and to a lesser extent in whole milk, probably retains some of the volatile and aromatic compounds as formed during ripening. But the fat itself seems to play a part. An artificial cream made by emulsifying fresh butterfat into skim milk gives by ripening results very similar to natural cream, whereas a cream with emulsified margarine fat has when ripened an aroma more akin to ripened skim milk. This suggests that butterfat in cream with its high content of glycerides containing radicals of low-molecular and water-soluble fatty acids may contribute some compounds in traces to the combined flavour, whereas this is not the case with margarine fat, when this contains acyl groups of C14 or higher molecular value. If the margarine fat contains coconut oil with its acyl groups of low molecular value, but no butyric acid radical, the ripened cream has a distinctive flavour, but sharp and unpleasant. It would appear that the butyric acid compounds in butterfat yield a trace of a derivative which contributes to the flavour, as little as a fraction of 1 mg per kg would be noticeable, and this view is supported by the studies of STEUART [118] who found free butyric acid and a compound with this acid in the steam distillate from a full-flavoured butter; he came to the conclusion that only when the butyric acid was present in the beta-position in added triglycerides was a pleasant flavour obtained. Such "butyro-fats" can be made by transesterification (see page 45), and when these fats are made into artificial creams and ripened with starter cultures it is possible to obtain flavour similar to those from genuine ripened cream. The transesterification process to ensure beta-butyric glycerides is, however, at present too difficult and costly to make the process of practical value. In the starter cultures themselves butyric compounds have not been found among the volatile aroma compounds, and the same is the case with ripened skim milk. It is not unlikely that in ripened cream, where there is always a slight hydrolysis of the butterfat, corresponding to 0·1–0·3 per cent free fatty acids, there would be a small trace of butyric acid.

Preparing Starter Cultures.—The development of a starter culture can be achieved in several ways. A method frequently used by margarine manufacturers, who receive whole milk unpasteurized but well cooled direct from farmers with healthy herds, is to select a mixed sample of good flavour and normal acidity, which gives a reductase test with methylene blue of not less than 12 hours and in the fermentation test gives an even gelatinous coagulate without gas bubbles and loose whey. When this milk is kept at 20–22° C until it is sour and shows an acidity of 36–40° S/H it is used for inoculating or seeding into skim milk from the same selected quality of whole milk, pasteurized for 30 minutes at 90–95 C and cooled to 20–22 C. About 1 per cent of seeding material is used and the skim milk then kept for ripening at 20–22°C. When ripe, this is again transplanted into similarly treated skim milk and transplantations repeated 3–4 times when the ripening time should be not more than 20–24 hours. The ripened milk is then tested for taste, aroma and acidity, 36–40° S/H, and volatile compounds by distillation, 30–35 ml decinormal alkali. If satisfactory, daily transplantations are carried on for about a week, while microscopic examinations by plate cultures are completed to indicate whether the culture is free from potential interfering organisms, particularly yeasts. If these bacteriological tests also are satisfactory the culture can be passed on for factory use.

Another method consists in cultivating the organisms from a sample of fine aromatic freshly made butter by seeding pasteurized skim milk with a small piece of the butter and carry on transplantations and tests as described above.

Starter cultures are also made by isolating the acid and the aroma organisms and cultivating them separately under their particular optimal conditions in sterile milk with daily transplantations. To get the aroma organisms to grow rapidly enough for this it is often necessary to add a vitamin B preparation, for example autolysed yeast, to the sterile milk, *ca.* 3–5 per cent. From these isolated pure cultures some strains of *Str. lactis* and of *Str. cremoris* are mixed with 2–3 times as many strains of aroma organisms and seeded into sterile milk and carried on by daily transplantations of 1 per cent for about a week; after this time transplantations are made into skim milk pasteurized for 30 minutes at 85–90°C to acclimatize the organisms to the type of milk used in the factory, and after daily transplantations at 1 per cent and cultivation at about 20°C the culture is evaluated by the usual criteria and should be ready for factory use.

The preparation of fresh starter cultures entails much work and care, and while factories with good milk supplies and bacteriological laboratories often develop their own starter cultures, some find it more convenient to obtain them from specialist laboratories, of which there are a number, and after a few transplantations for acclimatization put them to use under factory conditions. It should always be a rule that starter cultures and intermediate transplantations in factories should be developed in genuine skim milk, not in skim milk reconstituted from powder. There are manufacturers who prefer to grow the starter and intermediate cultures in whole milk, believing that the cream layer which forms on the top during development helps to develop and retain the aroma, but this system is rare.

Well prepared and controlled starter cultures are usually free from contamination with organisms which interfere with their proper function; it is, however, useful to submit them to periodical bacteriological examination by means of plate or slope culture tests on suitable media to search for the presence of any infection, which while not causing any interference in the starter might do so if introduced into the margarine by the milk and there find more favourable conditions for development. Direct microscopical tests of the starter are not very informative owing to the vast preponderance of the culture organisms, which is of the order of 100–200 millions per ml.

Ripening of Margarine Milk in Practice.—As a precaution against unexpected failures or irregularities it is advisable to have available in the margarine factory 3–4 starter cultures. Some factories run a dozen or more.

These are kept active by daily transplantations in fresh skim milk which has been pasteurized at 90–95 C for 30 minutes and cooled to ripening temperature which varies with circumstances, but is usually 20–25 C. 1 per cent inoculum is normally satisfactory and should give a firm gelatinous curd and good aroma in 18–24 hours. After ripening the culture should be kept below 8°C until required for transplantation. If it is found that satisfactory ripening takes at its usual temperature more than the 24 hours needed for daily transplantation it is better to increase the percentage of inoculum than to increase the ripening temperature. If inoculation with 3 per cent starter still gives too slow ripening, the starter may be considered too weak. In recent years the occasional use on farms of antibiotics of the penicillin type has led to traces of this passing into the milk and, though difficult to detect analytically in such minute traces, cause interference with the regular development of the culture organisms. Only the use of penicillin-resistant strains would overcome this. It is, however, simpler to ensure that milk is obtained from farms or dairies where contact with antibiotics is excluded.

Starter cultures are conveniently kept in thermostats in quantities of 100–200 ml in flasks with stoppers of sterilized cotton wool; a suitable type is the conical Erlenmeyer flask, because the relatively small top surface helps to maintain the anaerobic nature of the fermentation.

From these starter cultures two, in some cases more, are selected for development in margarine milk, which may take 3–4 propagation stages, depending on the quantities required.

For example, a starter culture, after 1–2 ml have been used for continuity propagation, can be inoculated at the rate of 1 per cent into 2 × 400 ml flasks for ripening at 23–24°C in skim milk pasteurized at 90–95°C. This will make 2 × 400 ml quantities available 24 hours later as Factory Starter, stage I.

These are then transplanted into larger quantities of similarly treated skim milk at the rate of 2 per cent and ripened in 2 × 20 litres (2 × 5 gallons) cans at 23–24°C. This stage might be called Factory Starter, stage II, and ripening is carried to the point of good gelatinous coagulation without signs of loose whey, which indicates that the ripening temperature has been too high. The pH value should be 4·5–4·8 (36–39° S H). This ripening stage usually takes 14–16 hours and the ripened milk is cooled below 8°C until used. A suitable vessel for this stage is a straight cylindrical can with loose cover, made of 18/8 stainless steel; it is placed in a water bath which permits the milk to be pasteurized, cooled to and kept at ripening temperature and cooled further down after ripening, if necessary by means of ice, without change of vessel. Before the 40 litres of Factory Starter, stage II, are used, the top layer of 3–5 cm of the ripened milk is skimmed off with a sterilized spoon in case adventitious infection from the air has contaminated the surface of the curd, and the contents are then thoroughly mixed and stirred with a sterilized hand-stirrer. About 2 × 18 litres are thus available for transplantation into the next stage.

If that stage is the milk for use in the margarine it is customary to use a higher ratio of inoculation, 4–6 per cent, to ensure the early establishment of acid conditions, partly as protection against growth of stray organisms from the air, partly to provide good conditions for development of aroma organisms. Some manufacturers go to a 10 per cent transplantation. If 5 per cent are used the 36 litres from stage II will yield 720 litres ripened margarine milk, and if two starter cultures are carried through 1440 litres will be available. If much larger quantities are required for the daily production of margarine, Factory Starter, stage II, can be used for developing by repetition a Factory Starter, stage III, from a 2 per cent transplantation, in which case this stage III will make available from each culture 1800 litres for transplantation into margarine milk to give, with 5 per cent inoculation, 36,000 litres ripened margarine milk.

It is, of course, also possible to develop from the original starter culture, grown in a 100 ml flask, a number of stage I bottles of 400 ml, as each needs only 4 ml for inoculation. If 6 × 400 ml Factory Starter, stage I, bottles are developed from each of the two selected starter cultures there will be 6 × 20 litre cans of Factory Starter, stage II, available at 2 per cent inoculation, and, after skimming the surface off, 6 × 18 litres will at 5 per cent inoculation give 2160 litres (about 475 gallons) margarine milk from each starter culture with two Factory Starter stages.

Some manufacturers may prefer different percentages of transplantation and other ripening temperatures, as their experience and their quality of milk available dictate. The above details are given by way of example and have been found successful in many factories with both their own developed cultures and with purchased starter cultures. In the latter case it is advisable to follow the directions from the makers, particularly if the purchased culture is obtained as a dry culture powder, which requires higher initial development temperatures; if they do not give full satisfaction, adjustments as to percentage of inoculum, ripening temperature, etc., may be necessary. Most purchased starter cultures have been produced for the purpose of cream ripening for butter or for acid development in cheese milk and they may need acclimatization to margarine milk.

Pasteurization temperatures and times vary a good deal; the rather high temperature and protracted periods mentioned above for starter cultures and the several stages of factory starters are widely used, partly because various bactericidal substances in milk are destroyed at 75–80°C, partly because they offer a greater chance of destroying certain thermo-resistant organisms, as for example the spore-forming *Bac. subtilis* and *Bac. mesentericus.*

The same considerations apply to the last stage of development, the preparation of margarine milk, although pasteurization at 80–85°C for 15–30 seconds is sufficient for an average good quality of skim milk. If pasteurization takes place before storage of the skim milk and this is stored below 8°C it should be brought up to ripening temperature immediately before inoculation; if pasteurized just before use it should be rapidly cooled to this temperature and inoculated at once. Ripening temperatures show fairly wide variations from factory to factory, but are mostly between 20 and 25°C. The percentage of inoculum also varies; it should not be under 3 per cent. nor over 10 per cent; a favoured amount is 5 per cent, when good quality skim milk with an approved factory starter should ripen in 12–15 hours at 20–22°C. The reason for the higher transplantation rate with margarine milk is the desirability to set up a vigorous acid formation as soon as possible, and for the lower ripening temperature of 20–22°C to give the aroma bacteria, whose optimum temperature it is, the best conditions for growth and functioning on the basis of the lactic acid formed.

Some manufacturers have found that a better aroma development takes place if 0·1–0·25 per cent citric acid, dissolved in water, is added to the milk after the starter has been distributed therein. The ripening of the margarine milk should be carried to a higher degree of acidity, a pH of 4·3–4·4 or titration acidity of 42–44° S/H. Before this stage the acid formation has slowed down and 0·8–1 per cent lactic acid is present, but aroma formation is still noticeable. Well ripened skim milk may by the usual tests show volatility titration figures of 30–35 ml decinormal NaOH and up to 25–30 mg diacetyl and 500–600 mg acetylmethylcarbinol per litre. Usually the result of the ripening is judged by flavour and aroma as well as titration for acidity, and if these criteria are satisfactory and the ripening period normal, the milk is cooled below 8°C until required for use. Such milk, when used to the extent of 10 per cent in the margarine emulsion, may after allowing for losses by volatility or biochemical reduction of some of the diacetyl introduce 1·5–2 mg of this aroma substance per kg margarine, which compares with the amount of 0·5–4 mg, mostly 1–1·5 mg per kg, found in aromatic butter from ripened cream. The time cycle of ripening should be arranged such that the ripened milk is not kept more than 3–4 hours before use; a margin must be allowed as ripening cannot always be regulated to a precise time-cycle. A slight and slow aroma development may take place even at the low storage temperature of the milk before use.

A method of ripening which is favoured by some manufacturers consists in initiating the process at 25–28°C in order to accelerate the growth of the acid-producing streptococci, and after some hours, 6–8, cool the milk gradually down to 20–22°C by passing cold water through the jacket or temperature regulating coil of the ripening vat, but without stirring. This method is claimed to give the aroma organisms improved conditions of development. Other manufacturers prefer to stir the ripening milk for 15–30 seconds every hour before it shows signs of curdling. The reason is that they believe the presence of some air in the ripening milk aids the development of diacetyl and prevents or retards its reduction to the slightly bitter butyleneglycol.

The benefit of the presence of air as an aid to diacetyl development in ripening cream and starters was observed by VIRTANEN and by HAMMER and HEDRICK, (see page 83) ref. [113] [114], and the method has also been applied to ripening of skim milk. There are several variations in details, but in principle the method is as follows: Skim milk after pasteurization and addition of 0·1–0·2 per cent citric acid is inoculated with 2–3 per cent factory starter and allowed to ripen at 24–26 C, which ensures a vigorous development of acid-producing streptococci. When a titration acidity of about 36° S/H is reached this acid milk is mixed with about twice the quantity of fresh pasteurized skim milk containing 0·1–0·2 per cent citric acid; the mixture will to begin with show an acidity of about 18–20° S/H and is ripened while it is being stirred mechanically at moderate speed, and a finely distributed current of cleaned, washed, preferably sterile, air is blown through from a perforated coil or an air diffuser at the bottom. The air pressure at the inlet depends on the depth of the vessel, but should not exceed 0·5–0·75 atm. gauge pressure to avoid troublesome frothing. Vertical jacketed ripening vessels are most suitable for this process. The temperature of this second ripening stage should preferably be a little lower than in the initial stage, for example 21–23°C, and the process is carried to full acidity of 40–42 S/H. The combined process with a good active starter takes 16–22 hours, and the ripened milk is then cooled to 8 C or less until used. There are in different factories minor differences in temperatures, ratio of inoculum and dilution after the first ripening stage, in air pressure and quantity, but in principle the process is as described. To minimize frothing some users of this process add about 0·5–1 per cent of whole milk to the skim milk for the first ripening stage, some add about 0·25 per cent sterile groundnut oil at the commencement of aeration; the fat alters the surface tension and checks frothing, which usually ceases when the full ripening acidity has developed. A head-space should be arranged in the ripening vessel to allow for frothing. By aeration the diacetyl content of the ripened milk is often as high as 30–35 mg per litre with about 700 mg of acetylmethylcarbinol.

To save the daily task of preparing factory starters of the various stages the ripened margarine milk is in some factories used for inoculation of quantities of fresh margarine milk. This system is preferably carried out in the vertical cylindrical closed type of ripening vat. Instead of withdrawing all the ripened margarine milk for use, an outlet is provided in the side of the ripening vat so that about 5 per cent of the ripened milk is retained; the vat is then refilled with fresh pasteurized or sterilized skim milk of 20–22 C which by the agitator is mixed with the retained ripened milk. The ripening temperature is regulated by a jacket which can also be supplied with cold or ice-cold water for cooling down after ripening. 18–22 hours is the normal ripening period. Certain precautions are necessary with this system. If the original factory starter, used for the first batch of margarine milk, has a slight infection, this is liable to accumulate in course of the week, and is particularly harmful if caused by lactose-fermenting torula yeasts; such a risk is obviated by the daily use of fresh starters in the more conventional method. An infection can also be introduced via the fresh milk supply. To eliminate this risk sterilized skim milk from plant of the type described on page 77 is used in some plants. Another point is the system of ripening. If this is carried to the stage of maximum aroma development, the acid-producers have commenced to weaken through the high acidity and are therefore at times sluggish in getting through the initial stage of the next ripening. This is sometimes overcome by starting the ripening at 25–26° C and cooling the mixture down to 20° C after 5–6 hours and maintaining this temperature to full ripening of 42–44° S/H.

The use of skim milk in the sterilized form is essential if the continuous ripening system is used. When manufacturers began to introduce continuous systems for emulsification and cooling continuous ripening was a logical desideratum, but many difficulties have to be surmounted in producing a good aromatic ripened milk by this method. The first step is to provide a continuous sterilizer with regular output of reliably sterilized milk that does not have a strong cooked taste, and that does not cause the formation of scale or a scorched deposit on the heating surface where the temperature is high. The treatment takes place under pressure as the milk must be heated to *ca.* 120° C, hence the temperature of the heating medium must be 125–126° C. The sterilizers of the plate type, mentioned on page 77, have been found suitable as they provide the desired very thin film of milk and a pressure system for rapid cooling. Great care is, however, necessary to avoid scale in the last section of the heater and the first section of the cooler. From the pressure sterilizer and cooler the milk is supplied in a continuous stream in a closed system, but reduced to atmospheric pressure, to the ripener. This is a vertical cylindrical jacketed vessel of stainless steel with domed top and bottom and with an agitator for moderate speed; the inlet is at the top, the outlet at the bottom; it has on the top a valve and vent which is connected to atmosphere through a sterile air filter, but can also be used for aseptic addition of the starter culture. The vessel is first steam sterilized and then filled to within 6 in. of the top with sterilized skim milk; the starter culture is added when the milk has the required ripening temperature, which is adjustable by the jacket, and is continually stirred at about 40 r.p.m. As the acidity increases, coagulation takes place in due course in a fine flocculent form. When the contents are ripened, for example to 40° S/H, a pump begins to withdraw the ripened milk for use in margarine and sterilized milk is admitted at the rate of withdrawal: By correct dimensioning of the system the acidity is maintained at the desired level. The temperature of ripening depends on the activity of the culture; 22–24° C have in practice been found suitable for many cultures and given a well-balanced development of both acid and aroma producers. The ripened milk is usually passed through a cooling system on the way to the emulsifiers. For an hourly output from the emulsifiers of one ton a ripening vessel of 3000–3500 litres capacity is suitable as this would correspond to a ripening period of about 18 hours. To ripen the milk continuously at falling temperatures a system as indicated diagrammatically in Fig. 22 has been proposed. *A* and *B* are two jacketed ripening vessels provided with propeller stirrers. The sterilized skim milk enters the first vessel at *C* and leaves at *D* through pipe *E* to enter the second vessel at *F* and leave as ripened milk at *G*. *V* and V^1 are vent pipes which can also be used as inlets for addition of starter cultures. *L* and L^1 are light-glasses. The procedure followed is as described above, but in the first vessel a temperature of 25–26°C is maintained to promote the growth of the acid-producing streptococci, whereas the second vessel is held at a lower temperature, 20–22°C, to give more favourable conditions for the aroma organisms.

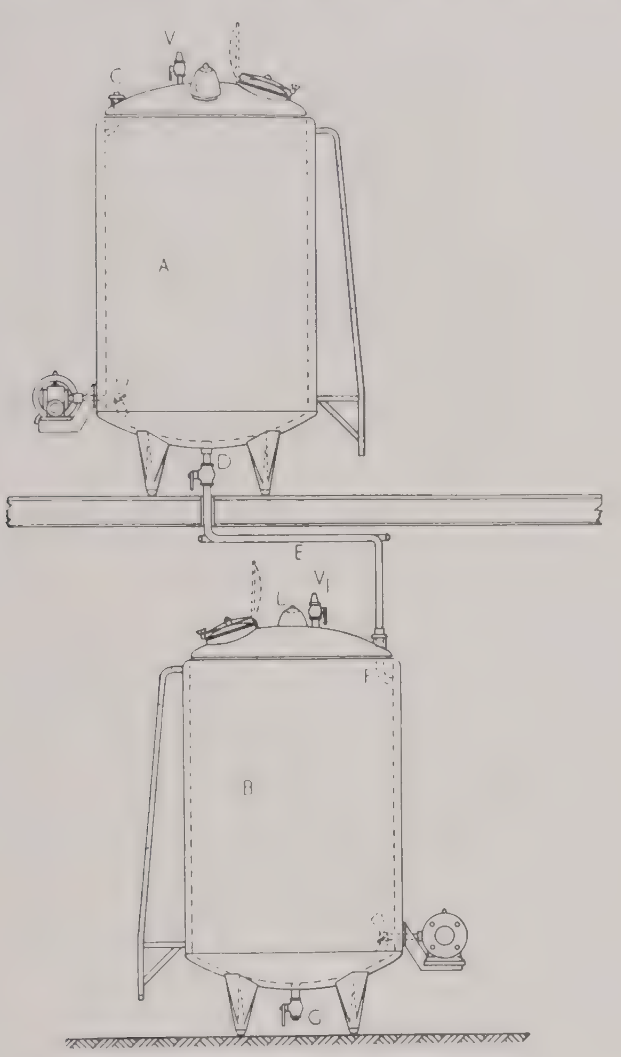


Fig. 22. Continuous ripener.

As these systems of continuous ripening require very careful bacteriological supervision, a delicate balance between throughput, activity of cultures and other conditions of ripening, as well as a regular supply of a good and uniform quality of skim milk it has not yet found wide application.

The use of a milk powder solution in place of fresh skim milk seems to cause difficulties in the regularity of ripening, even if citric acid is added to the solution.

Before the biochemistry of ripening was elucidated during the last two or three decades many different micro-organisms were tried by themselves or in conjunction with various known lactic acid organisms to develop special flavours and qualities in the milk. Various micrococci and rod-shaped bacteria of the *Bacillus bulgaricus* type, the mixed yeasts and lactic acid bacteria of the aromatic milk drink Koumiss from Russia, or of Kefir, a similar drink from Caucasus, and several others have been used in some factories. Some of these cause a slight alcoholic fermentation in addition to lactic acid development, but none give a good butter aroma. Some micrococci which form mucus from the milk protein or some lactic acid forming streptococci, which form mucus from the sugar present, have been used in some places in a pre-fermentation followed by a lactic acid fermentation with *Str. lactis*, the advantage claimed being the enhanced emulsifying properties of such milk through the presence of mucilage. The flavour is, however, rarely good and the methods are probably now only of historical interest.

With a fermentation process such as ripening of milk, where success depends on many factors, including the correct balance and symbiosis of several strains of bacteria, irregularities may occur unless keen attention to details is maintained. A gradual weakening of one or other of the strains may slowly take place, or infection or degeneration of the type may set in, or the process of acid-development, and thus aroma formation may be slowed down or be brought to a stop by infection with bacteriophage, a virus-like growth much smaller than the bacteria, which attacks them and destroys the cells, and because of its small size cannot be detected by the ordinary microscope, but through its effect. If a starter culture, or later development stages from it, are found infected they must be eliminated, the vessels used thoroughly sterilized and new starter cultures introduced. The described system of running several cultures and starters insures against total stoppage.

Another fault occasionally encountered is the development of a malty flavour as the result of the presence of *Str. maltigenes*, which by some bacteriologists is looked upon as a degenerated form or mutant of *Str. lactis*, by others as a separate variety. In microscopical appearance it is very similar to *Str. lactis* and difficult to distinguish except by the flavour, which gradually intensifies in course of some transplantations and is difficult to eliminate. A thorough infection may have set in before detected and a complete discard of the culture responsible is essential. As insurance against interference with production from this cause the multiple starter culture system is useful.

Other infections to guard against, and not uncommon in spite of all practical precautions, are yeasts, particularly the lactose fermenting *toru-*

laceae and those with lipolytic properties, moulds and lipolytic bacteria. The system of bacteriological control will be described in the section about Process Control.

When as the result of the work by VAN NIEL *et al.* (page 82) [112], it was realised that diacetyl and acetylmethylcarbinol formed important parts of butter aroma, it was logical to add these compounds as chemicals to ripened milk where insufficient had been developed by the natural process. This is also done sometimes with ripened cream, but has been a much more important method for margarine milk. The correct amount to add should be such as to ensure the presence in margarine of 1–3 mg per kg, which matches good aromatic butter; an excess leads to an unbalanced flavour.

A so-called "chemical ripening" process without the culture organisms is occasionally used. With the normal culture the risk exists, that for some reason it is thrown out of balance and that excessive effect of the reductase activity of the acid-formers causes some of the formed diacetyl to be reduced to the aromaless slightly bitter tasting butyleneglycol. By addition to fresh pasteurized skim milk of lactic acid to give a pH of 4·3–4·5 and of a mixture of formic, acetic, citric and propionic acids as well as diacetyl in the proportions these compounds are found in well ripened milk the ripening process is entirely dispensed with and much work and worry avoided [119]. The "chemically ripened" milk can be prepared for use when required instead of 16–24 hours earlier. This method sounds simple and tempting, but is criticized on three grounds. Firstly, it is costly as several of the ingredients are expensive compared with the cost of making them by culture organisms; secondly, the stray organisms surviving pasteurization or gaining access from the air or plant have the field to themselves without competition from the cultures for the nutrients; thirdly, butter aroma contains something more than the mentioned chemicals and at present unknown; the flavour and aroma by this chemical ripening is therefore less mature and mellow. Much labour and plant cost is, however, saved.

It has been proposed to introduce a suitable flavour and aroma in butter, made from unripened cream, by adding a steam distillate from a ripened starter culture. While this may be economical with butter the suggested application of this method to margarine emulsified with water is too cumbersome and costly compared with other methods and the margarine will lack the milk solids which are valued for other reasons.

The introduction into margarine of flavouring and aromatizing ingredients not derived from milk will be dealt with in the section about Ingredients.

Different opinions are held about the right degree of acidity in the margarine milk and in the margarine serum. A full ripening acidity of 40–42 S/H or a pH of 4·3–4·5 has often been considered responsible for premature incipient oxidative rancidity and "fishy" taste in the margarine, particularly in salted margarine with 0·6 per cent salt or more. This has definitely been found to be the case with butter, and it applies also to, at any rate some, margarine fat compositions. Some manufacturers have tried to overcome this difficulty by stopping the ripening process at an early stage, but this has the disadvantage of not allowing aroma development, and by leaving the milk at low acidity stray infections have a better chance of growing. A better practice consists in allowing intensive aroma development and using less milk in the margarine, making up the full aqueous phase by adding sterile water to the milk immediately before emulsification. Some manufacturers mix fully ripened milk with pasteurized unripened milk and thus reduce the acidity of the aqueous phase. For example, 50 per cent fully ripened milk and 50 per cent unripened milk will give a pH value of about 5·4 or an acidity of 24° S/H, 20 per cent fully ripened milk and 80 per cent unripened will give pH about 6 and an acidity of *ca.* 14° S/H.

Sometimes the skim milk is diluted with water before the factory starter is added for ripening the margarine milk, for example by using equal volumes of skim milk and water, but by thus altering the nutritive basis for the organisms their balanced symbiosis is easily upset and it is more difficult to achieve a strong aroma.

The most frequently used method of reducing the acidity, when the manufacturer wishes to use a relatively large percentage of milk in the margarine, is neutralization of all or part of the acidity when ripening is complete. Carbonate of soda, bicarbonate of soda, calcium hydroxide or dilute caustic soda are used as neutralizing materials. Usually the acidity is reduced to a pH of 5·4–6·2, corresponding when caustic soda is used for neutralization to an acidity of about 28° S/H to 20° S/H. As the amount of caustic soda for such reductions in acidity would only be 0·13–2·3 per cent of the weight of the ripened milk it would, even in very dilute form, cause very little dilution of the aroma compounds, compared with the use of unripened milk or water for the reduction of acidity. The milk should be cooled to less than 10° C as soon as possible to prevent the lactic acid streptococci becoming active again in the partially neutralized milk.

What has been stated about treatment of skim milk for margarine applies in general also to reconstituted skim milk from spray-dried powder. As the margarine manufacturer rarely has control of the milk used for the powder, the process by which it is made and its storage conditions, and as its age may vary considerably, the results of ripening are often a little different from natural skim milk. Although the usual chemical tests may show a normal composition as to major constituents, there may be a deficiency in important nutritive trace factors, such as members of the vitamin B complex. In addition to chemical and bacteriological tests the powder should be examined by small-scale ripening tests with different culture starters, as these may show some difference in reaction to the powder solution. The addition of 0·1–0·2 per cent citric acid is frequently very beneficial, as is the addition of some vitamin B factors, but where these are obtained from some "combined" sources such as yeast or liver autolysate the taste is usually too strong and the preparations expensive. When sufficiently cheap preparations of synthetic vitamin B factors which are generally comparatively tasteless are available, they may be of interest in this connection and ensure greater certainty of a fully satisfactory ripened quality from milk powder.

At present the initial and intermediary stages of starter development are nearly always for safety's sake carried through in genuine skim milk and the powder solution only used in the final margarine milk stage. As a rule the cultures maintain their activity and balance through this one stage, but experience may suggest some modification in temperature of ripening and percentage of inoculum.

Plant for Ripening.—While the original starter cultures, or mother starters, are usually kept in small glass flasks in laboratories or separate propagation rooms, the first factory starter stage, if the container required is less than one litre, is either in similar shaped glass flasks or in small metal containers with vented lid. Glass containers are generally favoured at this stage as they allow easier inspection of the curd formation.

For the next stage, Factory Starter, stage II, where containers of 15–25 litres are mostly used, a suitable type is a stainless steel cylindrical can with lid. Two or more of these are set in a water bath where pasteurization in hot water, cooling, ripening and final cooling and storing in an ice-water mixture takes place. Stirring of the milk during heating and cooling and after ripening is usually with a detached hand-stirrer with a perforated plate at the end. Fig. 23 shows two types of starter cans of 15–25 litres content in a water-bath; can *A* has a push-in lid with handle and vent holes, can *B* has a lid sitting in a water seal and a vent pipe plugged with sterile cotton wool and covered by a loose cap. Fig. 24 shows a Silkeborg waterbath and thermostat arranged for two cans of starter stage II type and for two smaller cans suitable for stage I starters; in this particular arrangement the temperature is electrically regulated.

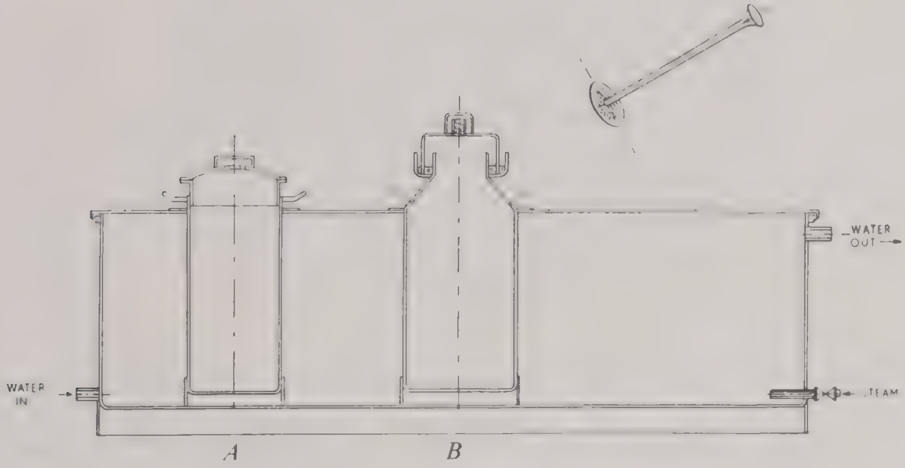


Fig. 23. Cans for starter cultures.

If a further intermediate stage, Factory Starter stage III, is required a smaller model of the ripener used for margarine milk can be used or a cylindrical vessel of stainless steel such as that shown in Fig. 20, page 76. It is an advantage that the vessel is constructed for use as pasteurizer, ripener and cooler; regulation of the temperature should be by means of a jacket and the vessel should be provided with a stirrer.

Ripening vats for margarine milk were earlier made of tinned steel and many of these are still in use. Modern plant is nearly always made of stainless steel and the extra cost of these is well worth while, as tin coatings deteriorate and the corrosive effect of acid milk on the steel causes formation of rust and lactates of iron which have a bitter taste and act as pro-oxidants in the margarine fats. Besides, some manufacturers dissolve the salt for the margarine in the ripened milk. This increases the corrosive effect on steel, and where this method is used stainless steel is practically essential. Tinned copper was at one time a much used material for dairy plant, but is now rightly avoided, as copper is a very strong pro-oxidant for fats.

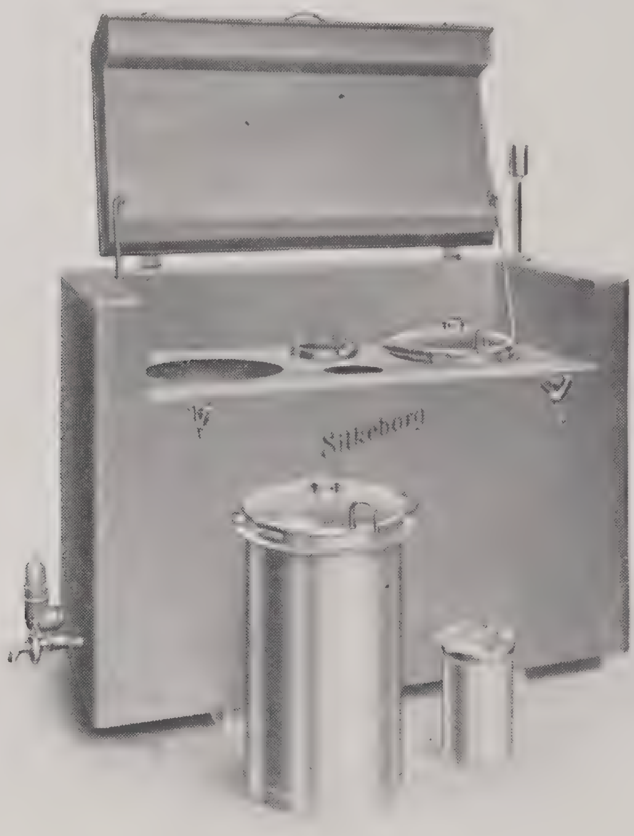


Fig. 24. Waterbath for starter cans (Courtesy: *Silkeborg Engineering Works*).

In smaller plants the rectangular type of ripening vat is often used. As shown in Fig. 25 it is a jacketed vat with the bottom sloping towards the outlet at one end. The jacket is filled with water which can be heated to boiling temperature, if wanted, by steam from a perforated pipe under the bottom of the vat. There is also at the bottom of the jacket a distributor pipe for cold water and the overflow is at the top. Stirring of the contents is by hand.

Ripening vats are, however, usually provided with mechanical stirrers. A very popular and efficient vat is the rectangular one with semi-cylindrical bottom as illustrated in Fig. 26. Like most modern ripeners it is made of stainless steel and is jacketed for water to regulate ripening temperature and fitted with an oscillating motor-driven coil for stirring and for brine or cold water circulation to cool the ripened milk below the temperature, where bacterial activity ceases or at which the milk is used for emulsification. The bearings for the coil are outside the vat. The covers of the vat in the illustration are hinged to the side so that when opened any condensate on them, caused by the low temperature of the contents drains off outside the vat and does not fall into the milk. Fig. 27 shows a modern installation of a number of such vats as well as the plate pasteurizer and cooler installation. in the background.

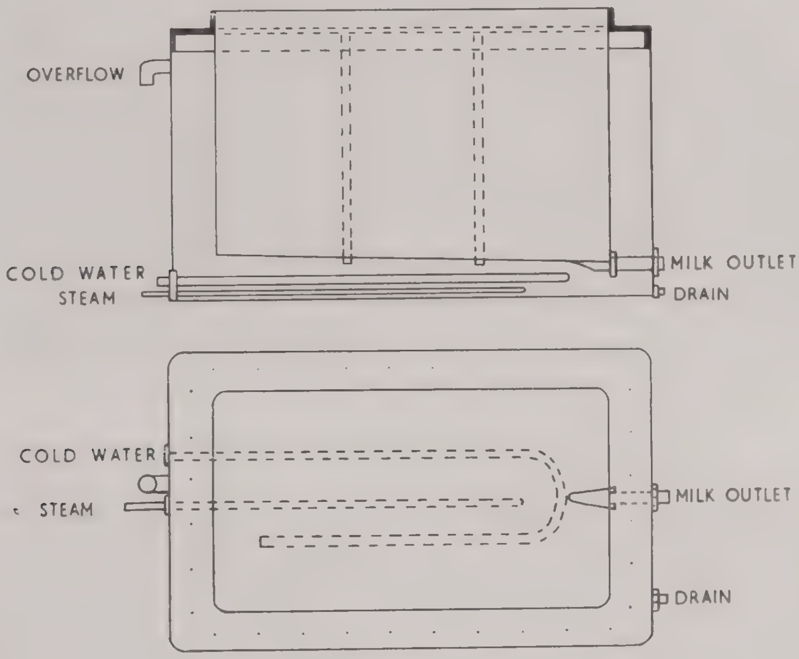


Fig. 25. Rectangular ripening vat.

Some ripening vats of similar general construction have an arrangement for lifting the cooling coil and suspending it above the vessel, so that it can be used as the final cooler for milk from flash pasteurizers of the older type after it has been passed through a regenerative heater for warming milk on the way to the pasteurizer. Such a ripener is shown in Fig. 28. When the vat is filled the coil is lowered into the vat to act as agitator for mixing in the starter and later for cooling the ripened milk.

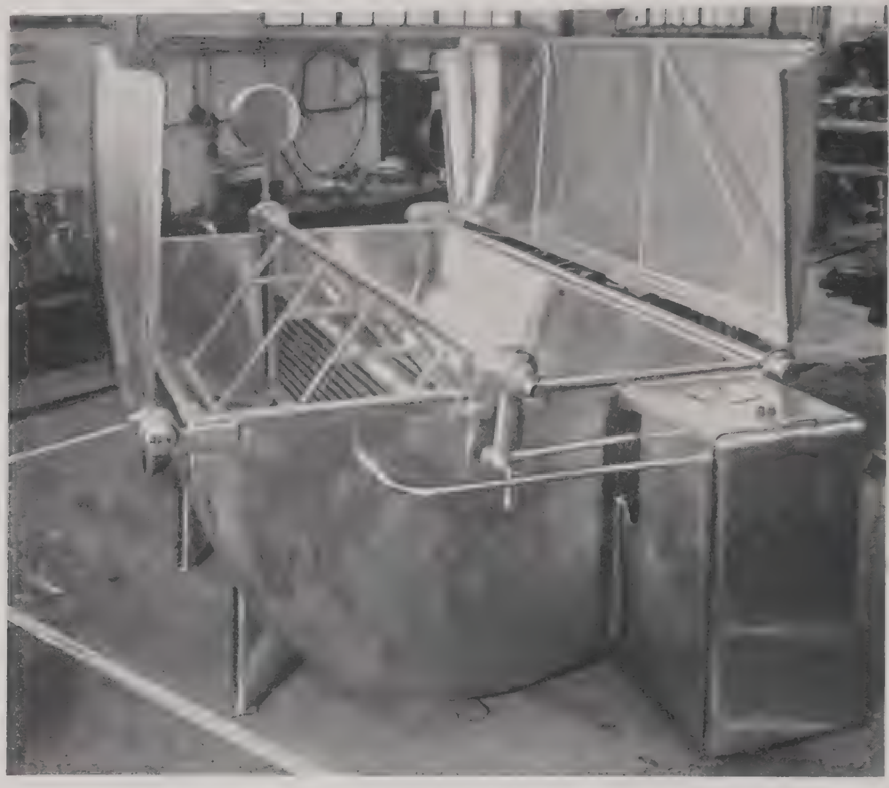


Fig. 26. Milk ripener with mechanical stirrer (Courtesy: *A.P.V.* Co. Ltd.).

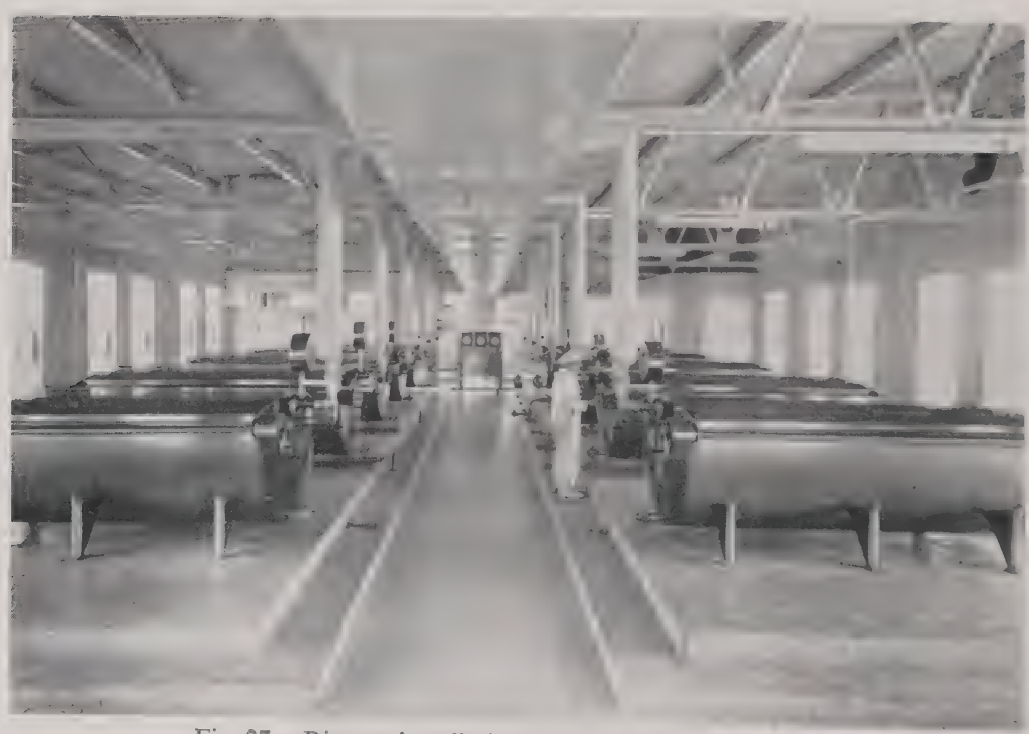


Fig. 27. Ripener installation (Courtesy: *Van den Berghs and Jurgens Ltd.*).

Many manufacturers prefer the vertical cylindrical type of ripener, an example of which is shown in Fig. 29. This was originally constructed for cream ripening, but is also very suitable for margarine milk. It is a cylindrical vat of stainless steel or aluminium surrounded by a steel tank insulated on the outside. The inner tank has a convex bottom sloping towards the outlet at the side and therefore drains well. In the middle of the tank is a vertical tube enclosing the shaft for the agitator which is rotated by motor and helical reduction gear under the tank. The shaft carries at the top, where it extends beyond the tube, a paddle frame shaped as an inverted U to which

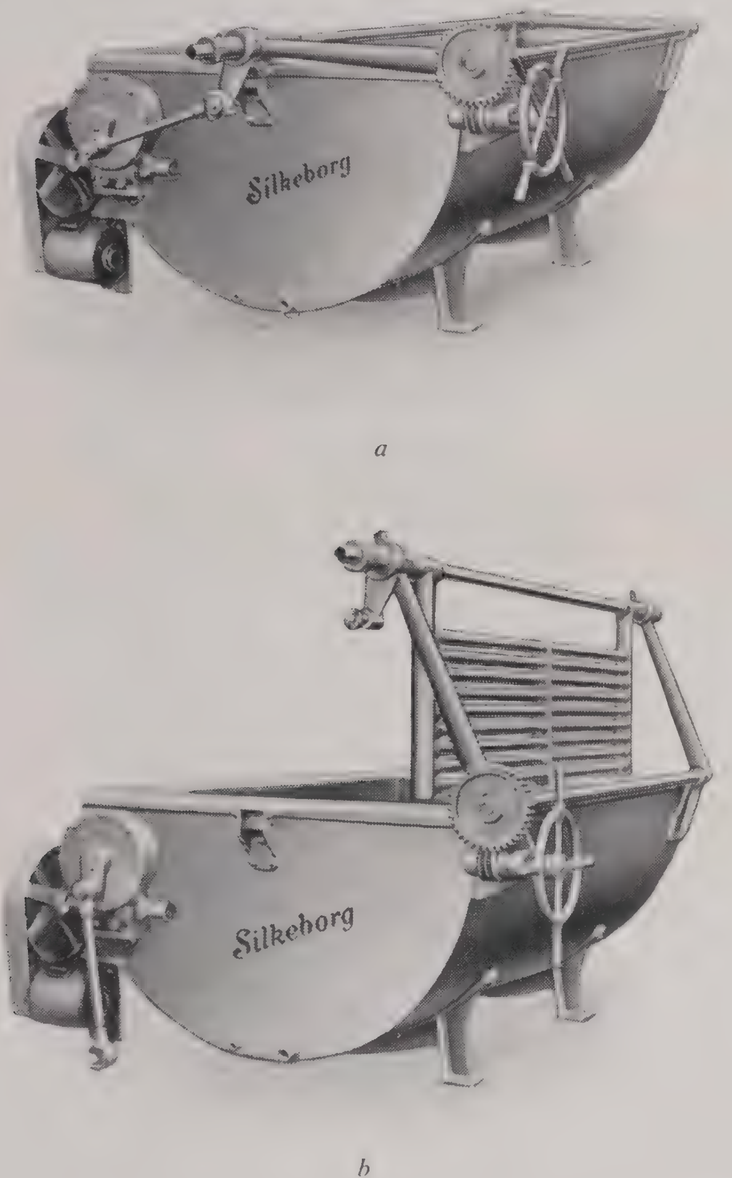


Fig. 28. Ripener with raised coil (Courtesy: *Silkeborg Engineering Works*).

paddle blades are fixed. The ripener has a hinged counterbalanced cover fixed to the outer cylinder. The inlet to the vat is through an opening in the cover. A thermometer on the side indicates the temperature of the contents and, if constructed as an electrical contact thermometer, can actuate the pump circulating warm or cold water through the jacket. A perforated distribution pipe round the top of the jacket causes the circulating water to flow down over the surface of the inner tank, and the circulating pump withdraws it from a pocket at the bottom. Regulation of the jacket temperature can be by manual or electrical control of a valve for injecting steam in the circulating water or of a pump for circulating brine through a plate heat exchanger through which the water passes. These ripening tanks are built in sizes from 750 to 3000 litres.

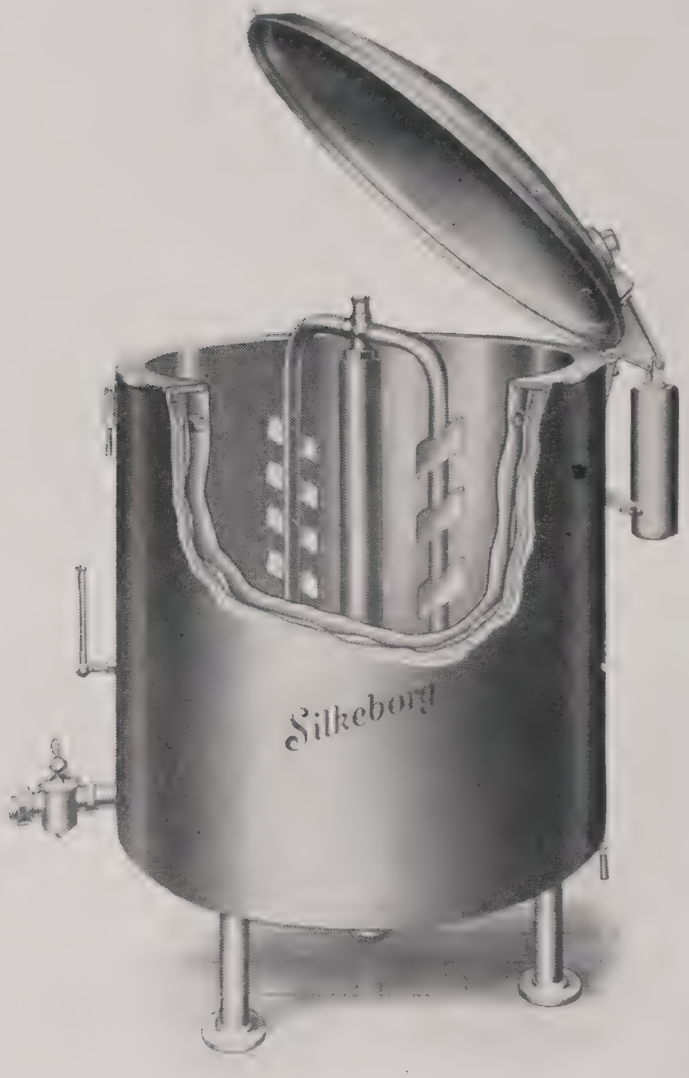


Fig. 29. Vertical cylindrical ripener (Courtesy: *Silkeborg Engineering Works*).

3. OTHER AQUEOUS RAW MATERIALS

Partly for cheapness, partly because some manufacturers believe that the casein in milk lessens the keeping quality of margarine, because of its value as a nutrient for proteolytic bacteria, whey has found application in some places as the aqueous phase. Sometimes it is obtained as a by-product from the manufacture of cheese after removal of the rennet-precipitated casein curd. As a mixed flora of bacteria as well as enzymes from the rennet are present in this product, it must be pasteurized at not less than 80°C and is then used as sweet whey of characteristic taste, which seems to be popular in certain regions; or it can be acidulated by inoculating it in the conventional way with a starter culture of lactic acid and aroma streptococci, as used for skim milk, which grows fairly well in whey, although not giving as pleasant and strong an aroma, possibly due to shortage of colloidal casein; the lactalbumen of whey is not a good nitrogen source for these organisms. The diacetyl content rarely exceeds 2–3 mg per litre.

Another method of producing whey and avoiding the specific flavour from rennet consists in precipitating the casein from skim milk by means of added lactic acid and heating to coagulation temperature. After separation from the casein the whey, which has an acidity of 12–15° S/H, is pasteurized and cooled to about 25°C; it is then inoculated with about 0·5 per cent starter and after 4–5 hours ripening cooled to 8–10°C before emulsification. The treatment with edible lactic acid is rather expensive, but the value of the acid-precipitated casein partly compensates for it.

Where margarine manufacture takes place in regions of highly developed dairying and butter production, which is the case in several European countries, buttermilk is often used in place of skim milk for margarine. If it is derived from churning of butter from culture-ripened cream and if it is cooled well down immediately after draining from the butter, it should be good enough bacteriologically to use direct in margarine. If because of transport and storage it has to be pasteurized, the taste and aroma suffer and the protein is apt to coagulate in rather hard grains. If buttermilk is used for margarine it should be withdrawn from the butter before the addition to the churn of wash-water. Much of the diacetyl and acetylmethylcarbinol and other aroma compounds from ripened cream pass into the buttermilk in the churning process, but the aroma gradually disappears under prolonged storage. As some of the volatile acids, particularly carbonic acid, are lost by the churning the acidity of fresh buttermilk is less than of ripened skim milk; some manufacturers make up the difference by adding a little lactic acid or citric acid. Most of the iron and lecithin compounds in milk pass into the cream in the separation process, and in the churning most again pass into the buttermilk. While the increased lecithin content probably is an advantage there has been evidence that the higher iron content can make margarine made with buttermilk more prone to oxidation than when made with skim milk. There is the possibility, though, that the greater stability with skim milk is due to a higher content of sulphydryl compounds in the proteins as these have anti-oxidant effect.

Where for statutory or other reasons milk or milk derivatives cannot be used as aqueous phase, water or water with various substances in solution or suspension is used. Many factories prefer to use sterile water, as even good drinking water with low bacterial content may provide a breeding ground for these when mixed with various ingredients and fat in the manufacturing process. As the refined fatty materials are practically tasteless, as is clean water, the mixture would be an insipid fatty product except for the salty taste, when salt is used; but there are countries and districts where unsalted margarine is demanded. Various ingredients are therefore added to the water to give this an attractive taste and some of the characteristics for margarine manufacture usually given by milk. These do not include the general ingredients mentioned in the next Section, such as salt and preservatives, emulsion stabilizers, aromatizing compounds, fat-soluble ingredients, etc.

As ingredients for improving the taste and character of the watery phase may be mentioned, lactose, 0·5–1 per cent, glucose, laevulose or saccharose 0·25–0·5 per cent, citric acid, 0·2–0·4 per cent, lactic acid, 0·1–0·3 per cent, or acetic acid, 0·1 per cent. Their use as taste improvers is a matter of individual preference, but as they are all natural food components no objection can be raised against their use. The acids give the margarine serum a slight acidity and thus make the conditions for development of a number of micro-organisms which cause a stale taste less favourable. The sugars help in the "browning" of the margarine by caramelization when used for frying, but they do not give the attractive aromatic granular sediment that milk gives. To imitate that, some factories make use of a suspension or colloidal solution in the water of 1–2 per cent defatted soya flour, soya protein or groundnut protein together with sugar; it gives on frying a fairly good, but rather coarse sediment; it has however often a bitter taste. The physical nature of the sediment is improved when balanced emulsion stabilizers are used in the margarine and when salt is present.

As a method of obtaining the benefit of ripened milk for flavouring and still use water as the aqueous phase for emulsification, the following procedure has at times been used in some factories, particularly when the fat-blend consisted largely of coconut or palmkernel oil: On the surface of 75 per cent of the liquified blend at about 35°C in a jacketed cylindrical vessel with slow agitator are distributed carefully 25 per cent of ripened milk heated to 35°C just before addition. The milk sinks slowly through the fat, which absorbs the aroma, and when the milk has settled at the bottom the two layers are mixed again by slow stirring. This is repeated 2–3 times during the first hour and the mixture is then left for final settling for 3–4 hours, the temperature being maintained to keep the fat fluid. The milk is then drained away and used for the manufacture of casein, and the fat is clarified and strained before being emulsified with water. This method is rather cumbersome, and unless a high price can be obtained for the casein as a by-product it is too costly to be of practical value nowadays. Equally good results are obtainable by simpler methods.

The patent literature shows many examples of aqueous phase compositions, for example soya milk, watery extract of almonds containing emulsin, suspensions of rye or wheat flour in water, solutions of casein in water, of lactates etc., but they have rarely been of practical value.

Ingredients and Auxiliary Materials

A number of ingredients and auxiliary materials are used in margarine, partly for its taste and aroma, partly to give it various physical and nutritional characteristics. In some countries certain specified additions have to be made as detector or indicator substances to assist the food control to recognize margarine by a simple test.

Some of the ingredients are soluble or dispersible in water, some are fat-soluble. In the batch process of manufacture they are mostly added in the emulsifier churn or at some later stage in the process; in the continuous process the water-soluble ingredients are usually added to the milk or other aqueous phase just before emulsification, while the fat-soluble materials are added in the blend composition tank or the blend tempering tank. In a few cases some ingredients are sprinkled on or injected into the product while moving through the process.

1. SALT

Salt is used principally for its taste; secondarily, it has a moderate preserving effect. In a few countries the taste of salted margarine is not liked and very little, 0·25–0·5 per cent, or nothing is used. In other countries there are minorities who want unsalted margarine, but by far the greater proportion of margarine contains salt in varying proportions, mostly from 1–2 per cent. There are, however, many regions where 2–3·5 per cent are wanted, and in some rare cases even 4–5 per cent.

The salt taste of margarine does not always reflect the proportion it contains. Being water-soluble the salt is found in the aqueous phase, and if this is extremely finely dispersed in the form of a water-in-fat emulsion the minute salty water globules are hampered by the surrounding fatty phase in giving the rapid taste response on the palate. A margarine with 3 per cent salt may in such cases taste no more salty than a margarine with "normal" dispersion containing 1–1·5 per cent salt. This point will be dealt with further in connection with emulsification.

If a margarine with the customary water content of 15–16 per cent contains 2 per cent salt, this is present in the aqueous phase at a concentration of about 13 per cent. This concentration is not high enough to prevent all bacterial or microbial growth in the aqueous phase where these organisms are found, as many of them have a high salt-tolerance, but it has a definite retarding effect on many, particularly some of the fat-splitting moulds and on water-carried bacteria such as *Bact. fluorescens liquefaciens*. The lactic acid streptococci, particularly the strong acid-formers, have low salt-tolerance; a concentration of 2·5 per cent salt has a slight inhibitory effect, 10 per cent stops growth, and the very large number present in freshly made margarine from ripened milk, many millions per ml, is in salted margarine reduced to a few per cent of the original in a few weeks. In addition to the salt the steadily diminishing amount of nutrients in the water droplets contributes to the gradual disappearance of bacterial life. Where unsalted margarine is made, milk is rarely used as the aqueous phase. In margarine containing 1 per cent salt, corresponding to 6–7 per cent in the water droplets, the preserving effect is small, though not negligible, particularly in countries where in addition chemical preservatives are allowed.

The salt should be of the best dairy grade quality, as for example described in British Standards Institution Specification B.S.I. 998. Where it is used as addition to the solidified margarine during kneading or blending operations, or in churns during emulsification, it should be in finely powdered form to ensure rapid solution in the water drops; at least 70 per cent should pass a 60-mesh sieve; coarse salt may cause grittiness in the product or local breaks in the emulsion which may show up as darker spots. If, as in the continuous process, salt is first dissolved in the milk just before emulsification the fineness of the particles is less important, but the purity must be of the usual high grade. If the margarine emulsion is made with a higher moisture content than the final margarine, the amount of salt required must be based on the concentration in the aqueous phase and not on the weight of the final margarine, so that allowance is made for loss through removal of excess moisture by kneading.

The salt should be dry, i.e., contain less than 0·1 per cent moisture so that it remains free from lumps and flows easily. It should be neutral or with a very small trace of alkalinity and free from alkaline earth compounds; even a trace of magnesia salts is harmful owing to their hygroscopic nature and bitter taste. It has been found [120] that traces of magnesium chloride can be the cause of accelerated oxidation of fat through the release of chlorine by hydroperoxides in the fat. A similar reaction is stated to take place, though to a minor extent, with sodium chloride in a strongly acid serum. Sulphates should be absent and iron, if present, should be less than 5 p.p.m. as iron compounds are strong pre-oxidants for fats, as are to a still greater degree copper compounds which must be rigidly excluded. The salt should be completely soluble and give a clean solution in water, free from scum and dust, which may have gained access from the packages, to which sufficient attention is not always paid. These should be dry, clean and moisture-proof and stored in a dry room. Damp sacking, though saturated with salt, permits the growth of various harmful micro-organisms which may get into the salt and later into the margarine when the sacks are emptied.

It is useful to check the taste of the salt by preparing a 3–5 per cent solution in water, which should be odourless and free from bitter aftertaste. To comply with the severe specification for purity the salt is mostly of the vacuum-concentrated and dried quality from subterranean deposits.

2. CHEMICAL PRESERVATIVES

The definition of a preservative is usually that it is a substance which inhibits the development of micro-organisms and sometimes destroys them. In Britain, preservatives are defined as any substance capable of inhibiting, retarding or arresting the process of fermentation, acidification or other decomposition of food, or mask the evidence of this, or neutralize the acid generated by such process. This is a very far-reaching definition and would appear at present to cover such compounds as added antioxidants, even though the same compounds may be present in the natural food, for example tocopherols in fats, citric acid in milk, ascorbic acid, etc. The principal types of deterioration in margarine is the hydrolytic rancidity, caused by micro-organisms, and the oxidative rancidity or tallowiness caused by air and accelerated by light. To prevent or retard the former chemical preservatives are permitted to be used in many countries, but prohibited in some. This chapter deals with the chemical preservatives; the subject of antioxidants will be discussed in a later chapter.

A number of chemical preservatives have been used in the past, sometimes under their chemical name, sometimes in various mixtures or under fancy-names. Because the use of preservatives is almost everywhere governed by statutory regulations manufacturers of margarine should insist on knowing the composition of proprietary products. Sodium fluoride which at the rate of 0·2 per cent is very effective is now prohibited almost everywhere. So are salicylate and formaldehyde, though less effective. Nitrates and sulphites are unsuitable. The only preservatives which have found extensive practical use in margarine and approval in many countries are boron compounds and benzoic acid and some of its derivatives. The use of benzoic acid preservatives is more wide-spread than of boron compounds. Details will be found in the chapter on statutory regulations.

Boron compounds, calculated, as boric acid H_3BO_3, were permitted in Britain to the extent of 0·5 per cent until 1926, when new preservative regulations prohibited its use—and any other preservative—but during the recent war and some post-war years permission to use this preservative in amounts up to 0·25 per cent was given as an emergency regulation to minimize the possibility of wastage by deterioration during storage. Boron preservatives are used either as boric acid, H_3BO_3, or as a sodium salt, usually borax, $Na_2B_4O_7,10H_2O$. The latter is much more soluble in water than boric acid. The proportions used are normally fixed by regulations and are as a rule 0·25–0·5 per cent. If, as is often the case, a mixture of boric acid and borax is used, partly because of the greater solubility, partly because it prevents the serum from becoming too acid, it should be remembered that the amount calculated as boric acid H_3BO_3 is less than the combined weight of the two constituents, as the boric acid equivalent in the hydrated borax is smaller. The chemicals should be of a grade suitable for edible use and the lead content be below 5 p.p.m., the arsenic below 2 p.p.m. Boron preservatives have when used in the mentioned proportions a fair bactericidal effect on many micro-organisms, particularly when salt is also present. Borax alone gives the serum a weak alkaline reaction which is undesirable. A much favoured mixture consists of approximately equal proportions of borax and boric acid, as with ripened milk it gives the serum an acidity of pH 6·6·8. This helps to give a fine dispersion of the aqueous phase in the fat which promotes keeping quality. In margarines containing high proportions of coconut oil or palm kernel oil in the fat-blend it is advisable to use a higher proportion of boric acid and less borax, or boric acid alone.

In many countries benzoic acid compounds are the preferred and permitted preservative for margarine. Benzoic acid is only very slightly soluble in water and sodium benzoate is therefore often used because of its easy solubility, but it is only bactericidal in acid solution as it is the benzoic acid that is effective and must be liberated from the sodium salt. Sometimes a mixture of the acid and the sodium salt is used, the acid being slightly soluble in fat. Benzoic acid is more effective against yeast than against moulds, and this together with its general effectiveness against many types of bacteria makes it a useful margarine preservative where the serum is acid. In neutral sera it is of little value, the acid being difficult to dissolve and the sodium salt remaining inactive. The proportions incorporated are usually 0·2–0·24 per cent, the lower figure applying to the acid, the higher to the sodium salt. The former is added as a very fine powder, the latter in aqueous solution.

In recent years other benzoic acid derivatives have been introduced and permitted in several countries, for example U.S.A. and Germany. They are the esters of *p*-hydroxybenzoic acid with methyl, ethyl or propyl alcohol, and the sodium salts of these. It has been found that the substitution in the para position of benzoic acid increases the bactericidal effect considerably, and these esters are used in smaller proportions, for example 0·08 per cent. The methyl ester, marketed under the name Nipagin, is particularly effective against moulds, whereas the propyl ester, Nipasol, is better against yeasts.

3. COLOURINGS AND DYES

Most countries now permit the colouring of margarine to the traditional butter yellow colour by means of added colourings and dyes. Butter is often similarly coloured artificially to ensure uniformity of colour, which if not thus standardized varies with the seasons and the feeding of the cows. The natural colour of butter is principally due to carotenoid compounds ingested with the food. The kind of colouring permitted in margarine is usually controlled by statutory regulations, which in some cases state what is permitted to be used, in others what is prohibited. The colourings may be classified as natural substances or as synthetic dyes.

Of the natural materials the most important is annatto, which is the only permitted artificial colouring for butter, cheese and margarine in some countries. It is obtained by extraction from the seed of *Bixa orellana*, the colouring substance being the carotenoid compound bixin. For use in margarine or butter the colouring matter which resides in the seed coating is taken up in a vegetable oil of edible quality and low cloudpoint, such as rape oil, soyabean oil or sunflower oil, and added to the margarine emulsion in the churn or to the fat-blend in the melting or tempering tanks. The colouring strength is usually standardized by the makers, but different brands often differ in strength. Annatto gives margarine a slightly pinkish yellow tint when the margarine serum is strongly acid and sometimes a little extract of the yellow colour from turmeric is added. Annatto is rather sensitive to light, which bleaches it, and may with certain serum ingredients show a very slight solubility in the aqueous phase. Annatto margarine and butter colouring is different from annatto cheese colouring which is water-soluble and extracted from the seed by alkalis.

In some countries where artificial colouring is prohibited the naturally deep orange-red variety of palm oil is used as part of the fat-blend. From certain districts on the Gold Coast and in Portuguese West Africa an oil is obtained which, when 0·3–0·5 per cent is added to the fat-blend, will give margarine an average butter-yellow colour. Most other palm oil varieties give too yellow a colour. This special oil can, however, only be very lightly refined, as a proper refining and deodorization treatment destroys most of the colour; consequently an addition of as little as 0·3 per cent can sometimes be detected by its violet-like flavour. The colour given by palm oil is also rather sensitive to light. It has the nutritional advantage that the β-carotene which is largely responsible for the orange-red colour of this oil imparts a vitamin A potency to the margarine corresponding to 3–5 international units per gram.

It has been shown recently that colouring of margarine can be effected by use of natural components of food, namely carotene and riboflavine. The carotene can be obtained by extraction with various solvents from carrots, lucerne and other green plants, and from red palm oil and can be highly concentrated, but need not be pure β-carotene. The concentrated extract is dissolved in a tasteless peroxide-free vegetable oil to a strength of about 2 per cent carotene, when an addition of about 0·1 per cent will give margarine a yellow colour, which is associated with the fatty phase. Riboflavin, vitamin B_2, is in its pure form an orange-yellow crystalline substance, soluble in water with a green fluorescence. In its natural form in association with milk, egg, yeast, etc., it is too expensive to extract for industrial use as a colouring substance, but the synthetic product is becoming available at a price that may permit its use in butter and margarine, if other colourings are not available. The vitamin B content it imparts when used for this purpose is hardly of nutritional significance. Used in a fine aqueous dispersion in the margarine it gives, owing to its fluorescence, a greenish tint of yellow which can be compensated by the use of an orange-yellow fat-soluble substance such as carotene or by the bixin of annatto colouring. It is therefore not suitable for use by itself, but with carotene solutions, red palm oil or annatto. It may be considered a drawback that it principally colours the aqueous phase, but this is not noticeable when the water is well dispersed in the fat, only when the margarine is used in the molten state. The fat-soluble carotene and the water-soluble riboflavine used together, but added as separate solutions for colouring margarine, give a better tint of yellow than when each is used alone [121]. Neither carotene nor riboflavine give very stable colours, but bleaching is largely avoided by suitable wrapping of the margarine. Red palm oil can, as already mentioned, be used as the carotene product, but the extracted purified carotene concentrate dissolved in a tasteless vegetable oil has a less pronounced flavour than the red palm oil product. The colouring strength of riboflavine is such that 3 p.p.m. in conjunction with 1·5 p.p.m. carotene will give a suitable tint to margarine.

At present the only fully satisfactory colouring substances for margarine as regards acid- and lightproofness, are some of the synthetic dyes made from coal tar derivatives. Some of the fat-soluble dyes of orange, red and yellow shades can give, singly or mixed, the tints required in all countries, and they are light- and acid-proof, i.e., they do not bleach on exposure of the margarine to light and are not affected by the acid, salt and other ingredients present in the margarine or by constituents in the customary wrapping materials. Very small proportions are needed to obtain the colour effect, 1 part dye to 20,000–30,000 parts margarine.

It is, of course, essential that no physiological objection can be raised against the dyes used. Certain medical circles have criticized the use of synthetic dyes for foodstuffs, and in the past dyes have sometimes been used which recently have been found harmful to certain experimental animals when administered in massive doses. Such dyes have been discarded years ago and reputable makers of dyes for food offer only those that have been found after exhaustive physiological tests to be unobjectionable. The dyes should also be free from impurities, and in many countries regulations limit the traces of lead and arsenic to 10 p.p.m. and 2 p.p.m. respectively. Margarine manufacturers, when buying dyes or solutions of dyes in vegetable oil, in which form the colourings are often marketed, should insist on a guarantee as to harmlessness and, still better, an additional declaration as to the kind of dye used. In U.S.A. the Federal Food, Drug and Cosmetic Act of 1938 specifies the coal tar dyes, which are harmless and suitable for use in various products, and in the list are included some for margarine. They are designated F. D. and C. colours, and each production of these has to be certified by the Authorities as to complying with the specification for purity. In U.S.A. the favoured yellow dyes for margarine are F. D. & C.

No. 3, phenyl-azo-β-naphthylamine, and F. D. & C. No. 4, o-tolyl-azo-β-naphthylamine, also known as Yellow A.B. and Yellow O.B. respectively.

In many other countries, in addition to Yellow A.B. and Yellow O.B., mixtures of the yellow dye benzene-azo-resorcinol and the red dye benzene-azo-β-naphthol are used to give the desired shade of yellow. Other mixtures are benzene-bis-azo-ortho-cresol with benzene-azo-β-naphthol, and ortho-toluene-azo-para-cresol with benzene-azo-β-naphthol. The use of varying mixtures of a yellow and a red or orange dye enables the user to compensate for variations in self-colour of the fat-blend for margarine and to meet the different consumer preferences as to the yellow tint of the finished product.

These dyes are used in an oil solution, but the solubility of the pure dyes is rather limited; in most vegetable oils it is only of the order of 1–3 per cent. The solution should be absolutely clear as any undissolved small particles of the dye, when added to the margarine, will cause dark spots. Margarine manufacturers who receive the dyes as very fine powders from the dye makers should test their solubility in oil at room temperature at a slightly higher concentration than required for dissolving them prior to addition to margarine. Similarly it is useful to test the lightproofness of the dye by colouring a sample of a semi-drying oil such as cottonseed oil with the dye to the strength of the solution for margarine and expose it in a test tube to strong daylight; it should show no tendency towards bleaching for at least 8 hours. The dyes are dissolved by adding the fine powder in the appropriate concentration to oil heated to 60–65°C. After 2–3 hours stirring at medium speed, 40–60 r.p.m., the solution is cooled to about 15°C and filtered; it should then remain clear. An oil which does not show any turbidity or deposit of "stearine" even at low warehouse temperature should be used as solvent. Some colour manufacturers use linseed oil, which is a good solvent, but not commendable for edible purposes owing to its strong drying properties; even a small proportion may catalyze oxidation in margarine. Rape oil, sunflower oil, soyabean oil, and sesame oil are more suitable; they should be of edible grade. Groundnut oil and particularly cottonseed oil show tendencies to deposit "stearine" in the cold. If a 2 per cent solution of dye in oil is used for colouring the fat-blend an addition of about 0·2 per cent in the fat or about 0·17 per cent on the margarine will give an average butter yellow colour. This corresponds to about 1 part dye per 25,000 parts margarine.

4. AROMA INGREDIENTS

Before the discovery that diacetyl is an important constituent of butter aroma (see page 82), many different natural and synthetic substances had been suggested from time to time as additives to margarine to impart a butter-like taste and aroma, or an attractive flavour which would be an improvement on the uncertain results from milk ripening, or be a substitute for this, where pasteurized unripened milk or a more or less flavourless aqueous phase was used. Most of these artificial aroma ingredients have ceased to be used: they included such compounds as essences of benzoic aldehyde, coumarin, vanillin, lactones of higher fatty acids, sodium and calcium salt of lactic acid, butyric acid and some of its salts and esters such as sodium butyrate and ethyl butyrate, isopropyl butyrate, mono-glycerol butyrate, etc. None of these gave a good imitation of the butter flavour, although some of the butyric acid compounds were acceptable in places where a strong slightly rancid butter flavour was popular. Some of these are still used, often now in mixtures with diacetyl, as for example in the Indian type of margarine, Vanaspati or vegetable ghee. The butyric acid preparations must be used in high dilution because of their pungent odour. Sodium butyrate, for example, not more than 5 p.p.m. if the margarine is intended for Western palates.

The increasing knowledge of the compounds of butter aroma from fully ripened cream and the important part played by diacetyl gave rise to the production of synthetic imitations, and patents were taken out for the process of aromatizing margarine with diacetyl [122]. Later EPSTEIN and HARRIS in U.S.A. patented the use of higher diketones with up to 8 carbon atoms [123]. These latter do not appear to have found widespread application, but diacetyl products are now in use in most margarine factories, where fully ripened milk is not relied on, or where it is desired to augment the naturally produced aroma by adding diacetyl.

The "chemical ripening" process is described on page 93 and the use in butter of an aroma distillate from ripened milk on page 93. It was a logical step to use a similar product for aromatizing margarine, but to obtain it by direct mixing of the known constituents as chemicals. The, so far, unknown minor compounds in "butter aroma" are either left out or "guessed at". Such a "chemical" aroma compound consists of a strong aqueous solution of lactic acid, citric acid, diacetyl, acetic acid, formic acid and a trace of propionic acid; in acid solution diacetyl is fairly stable. The amount added to margarine depends on the concentration of the solution and at which stage it is added. If added when all excess moisture has been removed from the margarine the ingredient should give a diacetyl content of 1–3 p.p.m. according to consumer preference. The commercial product Buttacid is of this type. Another diacetyl preparation is simply an aqueous solution of diacetyl acidified with a little citric acid to increase the stability.

The aroma bacteria, *Betacoccus cremoris*, *Str. diacetilactis*, *Str. aromaticus*, etc., always produce in ripening milk acetoin (acetylmethylcarbinol) in addition to diacetyl. Although acetoin is odourless by itself it has some function, not fully explained, in connection with the production of diacetyl and is present in the ripened milk in much larger proportions than diacetyl, 10–30 times as much. It has been suggested that in some way it may form a reservoir for biological oxidation to diacetyl, although this reaction does not take place by straight oxidation. Experience has shown that "aromas" containing both diacetyl and acetoin give a more lasting mellow butter-like taste and odour, and several aromatizing products are based on a combination of the two chemicals. For example, 88 per cent acetoin, 10 per cent diacetyl and 2 per cent citric acid makes a suitable mixture; it is usually supplied as a 10 per cent solution in water, the citric acid being added principally as a stabilizer. When used, the solution is still further diluted before being added to the margarine. An addition of 150 g of the 10 per cent solution will give an appropriate concentration in 1 ton margarine of about 1·5 p.p.m. diacetyl. Other acids such as tartaric or lactic acids are sometimes used as stabilizers. On the assumption that the butyric acid glycerides in butterfat plays a part in the development of aroma in butter from ripened cream (see page 84) this acid is sometimes used in addition to one of the stabilizing acids as, for example, in a mixture of 86 per cent acetoin, 10 per cent diacetyl, 2 per cent butyric acid and 2 per cent citric acid. Such a mixed product gives particularly good results when used as part substitute for ripened milk, the balance of which may provide some of the missing unidentified aroma compounds and also give the acid medium in which diacetyl keeps best. If unripened milk or water is used as aqueous phase, the addition of a small amount of acid, such as about 0·2 per cent of lactic acid, or a little acid phosphate, is recommended.

With reconstituted skim milk or with whey, where it is difficult to get the the same aroma development as with fresh skim milk, the use of a composite aroma as described has given results which are difficult to achieve without it.

A number of proprietary "butter aromas" of secret composition are on the market; most of them incorporate diacetyl in various proportions as well as butyric acid compounds as major constituents. Acetates, amyl esters, coumarin and vanillin are often detected. Some of these products are however meant to exercise their function more in the food preparations in which margarine is used than in margarine itself.

5. EGG YOLK AND LECITHIN

These ingredients are used in margarine principally to give it certain valued culinary properties which depend partly on the state of emulsion in the finished margarine, partly on its content of non-fatty solids.

When butter is used for frying in shallow pans, the water begins soon after the butter is melted to evaporate by steady boiling under the formation of a fine foam of small water bubbles, the membranes of which carry by flotation fine particles of the milk solids. There is practically no spattering and the water vapours escape regularly from the surface with a slight hissing sound. The fineness of the emulsion and the interfacial tension between fat and serum, regulated probably by a protein-lecithin complex, are the principal conditions for the steady boiling off of the water. When most of the water is evaporated the fat-insoluble milk solids as well as the salt begin to form a sediment, initially light brown, but, when after the removal of all the water the temperature goes up, darkening to a blackish brown very fine powder of pleasant roasting aroma. It consists of the coagulated dehydrated proteins, caramelized sugars, milk salts and added salt.

Margarine made with milk gives a similar, but coarser, sometimes lumpy, sediment and water boils off with some spattering from the surface without a foam layer, unless anti-spattering ingredients are added, which also assist in making the sediment finer as the result of the finer dispersion of the water droplets in the margarine, which their incorporation effects. Margarine made with whey behaves similarly, but gives much less sediment, and when made with water it spatters very badly and gives no sediment, except a greyish one if salt has been added.

Egg yolk was the first ingredient introduced to improve margarine for frying, and it is still widely used. An addition of 0·3–1 per cent liquid egg yolk gives margarine frying properties similar to those of butter. When used with whey or water margarine it is often mixed with a little glucose or laevulose, 0·2–0·4 per cent, to give a more voluminous sediment, but although egg yolk itself gives a small protein sediment in frying, it does not, even with sugar, equal in quantity and quality that given with milk, but the ingredient improves the margarine emulsion considerably. Liquid fresh egg yolk is the best both in flavour and in dispersing properties, but most factories must draw their supplies from distant regions—China used to be the chief source—and it was obtained strongly preserved with salt, boric acid or benzoic acid, according to the regulations of the country of use. In recent years, owing to the stringent preservative regulations in many countries, it is more customary to preserve it by spray-drying or by freezing; both methods seem to have impaired slightly the valued physical properties for margarine. From the way egg yolk acts in giving good frying properties to margarine it is clear that it is a good emulsion stabilizer; further reference to this will be made in that section.

Egg yolk is a very perishable substance and is easily attacked by microorganisms. Even if preserved by the various methods referred to it is rarely sterile and can be the cause of infection in margarine. A well-ripened milk gives usually a sufficiently strong protection by its lactic acid bacteria to minimize the risk of trouble from the egg yolk, but it is different with water. In any case, many manufacturers prefer to add the egg yolk to the milk or water and pasteurize them together, but if pasteurization is at high temperature the egg yolk loses some of its valuable physical properties.

The special effect of egg yolk has been attributed to its relatively high lecithin or phosphatide and sterol content. It was therefore logical to extract the phosphatides and cholesterol from egg yolk and thus obtain a much less perishable product serving the same purpose. Some of the best known preparations of this type were the proprietary brands Ovomargin and Heliocithin which were sterile and in very small proportions in margarine were stated to have the same effect as fresh egg yolk. The proportion of Ovomargin was usually about 0·05 per cent and of Heliocithin as little as 0·006-0·01 per cent. With such small quantities it is advisable to dilute them first with 3–4 times as much liquid oil. While they showed a very favourable effect on browning and sediment in milk margarine their emulsion stabilization was not equal to that of egg yolk itself; possibly some of the surface-active compounds of the protein and lecithin complexes in egg yolk were changed or lost in the extraction process.

The early lecithin preparations from egg yolk were rather expensive, and there were at times practical difficulties in getting them uniformly dispersed in the margarine; their use was therefore limited. The use of lecithin in margarine became, however, practically universal when "soya lecithin" was placed on the market. This is a by-product from the extraction of oil from soya beans and, to a much lesser extent, from some other oilseeds. Crude soya bean oil contains up to 2·5 per cent of mixed phosphatides, generally referred to as soya lecithin. It is in colloidal solution in the oil, but is precipitated by hydration, when steam is blown through the oil to remove remnants of solvent, or when about 5 per cent water is injected into the oil. Removal of lecithin reduces refining losses. The wetted oil is passed through special centrifuges to separate the clear oil from a wet lecithin sludge, which is dried in vacuum and often bleached at the same time, for example with hydrogen peroxide. The finished product is a light brown to dark brown very viscous substance, the commercial product usually containing 60–65 per cent "phosphatides", 30–35 per cent oil and about 5 per cent sterol. A similar product, but in inferior yield and quality is obtainable from groundnut, cottonseed and rape oils. The commercial product can be further concentrated and purified by extraction with acetone in which lecithin is insoluble. The commercial bleached soyabean product is the quality mostly used for margarine; it is sometimes diluted with refined oil and deodorised by being sprayed into a vacuum vessel at moderate temperature, when there is some removal of volatile odoriferous compounds by flashing; the conventional steam deodorization in vacuum is difficult because of foaming. If however, the lecithin is obtained by extraction of good quality beans, the miscella well filtered and the solvent removed at low temperature, partly in vacuum, a high-grade commercial edible quality is obtained, containing about 65–75 per cent phosphatides, which needs no further refining before use in margarine. It is advisable to dilute this product with 3–4 times as much refined deodorized oil for better dispersion in the margarine emulsion or in the fat-blend. The proportion used of the commercial (65 per cent) lecithin is usually 0·2–0·3 per cent or 0·75-1 per cent of the diluted material of 20 per cent concentration.

These so-called vegetable lecithins are highly valued ingredients in margarine and help in checking spattering and in forming a fine powdery sediment in milk margarine during frying; it does not itself contribute to a curd, as sometimes erroneously thought, when used in water margarine. It is not as effective as 0·3–0·5 per cent egg yolk and has by itself only a moderate effect as emulsion stabilizer. It has other advantages, as in certain cases it improves the texture of the margarine and it can in combination with certain other compounds act as an antioxidant when fresh, but if it contains deteriorated or oxidized fatty compounds it can have the opposite effect.

Egg yolk and lecithin were originally introduced as "browning" aids, but as mentioned they form little or no curd themselves. If a curd sediment is required in frying, which is generally the case with shallow pan frying, the margarine if not made with milk must contain some non-fatty solids of protein and carbohydrates. The latter by themselves, in the form of sugars, do not give a good sediment, as the caramelization at the frying temperature leads to the formation of a sticky substance, sometimes of rather bitter taste. But in combination with proteins fairly good results are obtained, particularly when such materials as de-fatted soya flour, groundnut protein or gluten-containing wheat flour is used and the serum is slightly acid, when some of the protein appears to be hydrolized to glutamic acid, which has a pleasant appetizing roast flavour. Ripened sour milk is, of course, the best curd and browning material, but mixtures from lactose, sucrose, lactic acid, citric acid, phosphoric acid, soya and wheat flours, etc., are fair substitutes. For curd-forming purposes the milk solids or their substitutes should be present in the margarine in proportions of 0·3–1 per cent. If the margarine is salted the "solids-not-fat" will be correspondingly increased. (See also page 290.)

As aids to, but not contributors to, curd sedimentation, anti-spattering and emulsion stabilization new synthetic and modified glyceride derivatives are now displacing egg yolk and to some extent lecithin in many factories; they have the advantage that they are sterile, do not support bacterial growth and are effective in very small proportions. They will be dealt with in detail under "Emulsion Stabilizers".

6. INDICATOR INGREDIENTS

Regulations in many countries demand the addition to margarine of certain ingredients, the presence of which can be ascertained by fairly simple tests and thereby provide control authorities with easy means of identifying margarine and the admixture of it, even in small proportions, to butter. The use of indicators was very helpful in the days, when analytical fat-chemistry was in its infancy, but with the modern methods of analysis there is no longer any real justification for imposing on the industry restrictions which can be burdensome, either through difficulties in obtaining a particular indicator or by being compelled to incorporate an ingredient which is a potential source of reduced keeping quality of the margarine. Modern analytical methods easily distinguish between butter and margarine and detect very small proportions of admixture.

Sesame oil was probably the first indicator used, as the Baudouin reaction is characteristic for this oil. By heating the oil with an equal volume of concentrated hydrochloric acid and a few drops of an alcoholic solution of furfural a strong red colour is given; as little as 0·5 per cent sesame oil in fatty mixtures can be detected in this way, provided the oil has not been heated to high temperatures, i.e., above 120–130 C during deodorization. Some countries stipulate the use of 10 per cent sesame oil in the fat-blend, others 5 per cent, 3 per cent or even 2 per cent. As however sesame oil varies in reactivity to the test and often does not respond at all, if the oil has been deodorized at the conventional temperatures for vegetable oils, because all or most of the reacting compound, sesamol, distils off with the odour compounds, it is essential for indicator purposes, that a minimum reactivity to the Baudouin test should be stipulated. This is done in certain countries by requiring that 0·5 per cent of the oil mixed with 99·5 per cent other oil should give a distinct red colour in the test; in other countries it is demanded that so much of the oil should be used in the fat-blend that a red colour to match a certain colour table standard is given by the margarine in the Baudouin test. This can be achieved for example by 2–3 per cent of oil deodorized at 120–130°C or by about 5 per cent deodorized at 150–160°C. There are, however, countries where the addition of sesame oil is required, but no reference to reactivity.

Another indicator ingredient specified in many countries, either by itself or in conjunction with sesame oil or as an alternative to this, is starch. When 0·2–0·5 per cent of this is dispersed in margarine the starch grains can usually be seen easily under the microscope or they are shown clearly by the blue colour given by an iodine solution. The starch ingredient in some cases is simply potato flour or wheat flour, in others potato starch or rice starch. The best place to incorporate this ingredient is the churn or the final blending operation. In the continuous process some difficulty is at times experienced in obtaining uniform distribution either by adding the starch to the aqueous or the fatty phase, unless adequate stirring is provided during the addition.

Until some years ago some countries, for example Austria and Hungary, specified the addition to margarine of 1 p.p.m. of dimethyl-amino-azobenzene, Butter Yellow, as indicator; it gives with acid a red colour. When a few years ago this dye was found to be carcinogenic, though in much heavier doses and on rats and mice, its use as margarine colouring and indicator was discontinued in most countries, and it is doubtful if it is used anywhere at present in foods.

From time to time other ingredients and chemicals have been suggested as indicators, but those mentioned are the principal and officially stipulated ones. Some countries, like Britain, Norway, Holland, U.S.A., Canada and others do not specify indicators, but rely on a well organized analytical food control to prevent adulteration. A wartime measure in Britain stipulated the use of starch in a cheap brand of margarine for rapid and easy check on compliance with price control.

7. VITAMIN CONCENTRATES

The development in nutritional science which led to the production of margarines "fortified" or enriched in nutritive value by means of added vitamins is mentioned on page 9 *et seq*. The only vitamins of practical importance in this connection are A and D, as in the other fat-soluble vitamins, E and K, as well as in "essential" fatty acids butter and margarine show no significant difference. Neither product is looked upon as a source of water-soluble vitamins; they are unnatural and unsuitable vehicles for these.

Published records of the vitamin content of butter show very wide variations. Apart from freak findings the divergence of results is partly due to lack in earlier years of standardized methods of test, physical and chemical as well as biological, partly to a real difference in samples from different seasons, different herds and different feeding régimes for the cows. Even now when tests have been much more specified and standardized there is a certain lack of precision and reproducibility of results which require some tolerance of interpretation. Another point to remember is the improvement, that has taken place in the vitamin content of butter, since the earlier observed wide variations made dairy farmers take steps to avoid extremes by more rational and nutritionally improved feeding of the cattle. There is, however, still a considerable difference in vitamin content of "winter butter" and "summer butter", from cattle fed on concentrates and those on pastures. Without taking the extremes, the vitamin content or potency of butter may be said to be 10–40 i.u.p.g. (international units per gram) A and 0·1–1·2 i.u.p.g. D. The comprehensive tables of Fixen and Roscoe on vitamins in food give averages for English summer butter as 27 i.u.p.g. A and 0·4–1 i.u.p.g. D. As, however, particularly in summer butter a considerable proportion, 20–40 per cent, of the vitamin A potency is due to β-carotene and this for humans is probably only worth one-half to one-third of vitamin A proper in vitamin effect, the 27 i.u.p.g. A is in reality only equivalent for humans to about 21 i.u.p.g. as real preformed vitamin A.

To vitaminize margarine to the nutritive equivalence of summer butter would therefore in Britain necessitate the addition of vitamin concentrate to give about 20 i.u.p.g. preformed vitamin A and 1 i.u.p.g. vitamin D. This is the standard which was made compulsory for all household margarine in Britain early in the recent war after having been adopted earlier voluntarily by some manufacturers. Later, owing to the war and special nutritional considerations, the vitamin D potency was increased to 3 i.u.p.g.

In U.S.A. the vitamin A potency was first 9,000 U.S.P. units per pound, corresponding to 16 i.u.p.g. A. Vitamin D was not usually added. The A potency has later been increased to about 26 i.u.p.g.

Other countries have adopted other standards in accordance with statutory regulations, recommendations of health authorities, or voluntary undertakings by manufacturers etc.; in some countries vitaminization of margarine is not considered necessary. The British standard has been adopted in many countries.

The source of vitamin A, in naturally strong or in concentrated preparations, was until recently entirely liver oil extracted from different kinds of fish and of whales. Some of these liver oils were also sources of vitamin D. During the last few years synthetic vitamin A has been made in practically pure form by various processes and is now available on the market as organic acid esters in oily solution.

Some sources of vitamin D have just been referred to. Their selection entailed practical difficulty as the ratios of A and D in these were quite different from those in butter and therefore from those required in margarine. The problem of the ratio was solved when it was discovered that vitamin D could be produced by exposure to light, of a certain wavelength, of ergosterol, for example from yeast, and the irradiated sterol could be purified and produced in pure crystalline form, calciferol, recently termed ergo-calciferol or vitamin D_2. This has a defined potency of 40 million international units D per g; it can be dissolved in a tasteless edible oil and used to adjust the A : D ratio of liver oil products or be combined in desired proportions with vitamin A products, such as shark liver oil, whale liver oil or solutions of synthetic A. Another D product is obtained by irradiation of a sterol, 7-dehydro-cholesterol, found as a minor constituent in cholesterol or produced synthetically. The irradiated compound, now termed cholecalciferol or vitamin D_3 is the vitamin D of milk and butter, is soluble in edible oil and for humans of same potency as vitamin D_2. Either can therefore be used in margarine with equal effect, though some animals utilize them differently. D_2 is at present a good deal cheaper than D_3.

A number of vitamin concentrates are now available for fortifying margarine. Liver oils with less than 10,000 i.u.p.g. vitamin A are now hardly worth considering as raw materials, as their strong flavour is only partly eliminated by the mild refining they can be given without destroying the vitamins, and the addition of 0·2–0·5 per cent to margarine, which would be needed to give this an A potency of 20 i.u.p.g. would be noticeable by the strong flavour. These oils are now mostly used for feeding stuffs. To overcome the flavour difficulty such oils would have to be saponified and the non-saponifiable matter, which includes the vitamins, extracted, purified and taken up in edible oil. This process is now rather uneconomic, but was used earlier.

For oils of medium potency, 10,000–40,000 i.u.p.g., various methods can be used for concentrating and separating the vitamins from the oil, for example adsorption on alumina or other suitable adsorbents and elution, selective liquid-liquid extraction with propane, and molecular distillation. In all these cases the concentrated vitamins are dissolved in a suitable vegetable edible oil, refined and deodorized by mild treatment and at moderate temperature if desired, and the oil solution standardized for potency. The commercial preparations for margarine are usually of 50,000–200,000 i.u.p.g. potency.

Natural oils of high potency such as whale liver and shark liver oils of more than 50,000 i.u.p.g. can often be used direct in margarine after cautious neutralization with carbonate or caustic soda, washing with hot water and deodorization at 120–130 C in high vacuum, which causes only minor process and potency loss.

As stated above synthetic methods have been developed for building up vitamin A from citral and other chemical compounds and reached industrial importance 4–5 years ago. The vitamin A is then used in the form of the acetate, butyrate, succinate, palmitate, laurate, etc., as it is more stable in the ester form, in which it is mostly found in natural sources. The vitamin A alcohol produced by saponification of liver oils and extraction of the non-saponifiable fraction is therefore also less stable. The pure crystalline vitamin A has a potency of about 3·2 million international units per g and is marketed as a solution of the ester in vegetable oil of high potency, or as a semi-crystalline product of about 1·5 million i.u.p.g. potency. The esters produced commercially are usually those with palmitic acid or acetic acid.

Vitamin A is fairly stable except when exposed to oxidizing agents such as air, peroxides, etc. As light catalyses oxidation in oil, vitamin A preparations should be protected against exposure to light and air. The oil used for diluting natural rich sources, or to dissolve and dilute the concentrated compound, should be carefully selected; oils rich in the natural antioxidant tocopherol, such as wheat germ oil or maize germ oil, are particularly suitable if fresh. Other useful oils are sesame oil, in which sesamol acts as an antioxidant, olive oil and groundnut oil, provided they are freshly refined and free from peroxides and oxidized constituents; rancid oils catalyse the destruction of vitamin A. Even when diluted with good oils vitamin A concentrates show sometimes a "dilution loss" of 5–15 per cent which may be real and caused by air in the oil or traces of peroxides, or it may be apparent and temporary. An added antioxidant such as hydroquinone, 0·05–0·1 per cent, is often added to increase the stability of vitamin concentrates, but it is not permitted everywhere for use in connection with foodstuffs.

Some fish liver oils are rich in both A and D and might therefore serve as sources of both vitamins for margarine, for example, halibut liver oil with 40,000–60,000 units A and 3,000–6,000 units D per g and tuna liver oil with 50,000–70,000 units A and 40,000–60,000 units D per g, but they are in limited supply and therefore of minor practical value for margarine, and they require adjustment for ratio with other oils. Tuna liver oil has, however, been the principal source of D in some countries, where the calciferol product has not been acceptable.

In most countries the source of D for concentrates for margarine is D_2 and, to a lesser extent, D_3, ergo-calciferol and chole-calciferol, in pure crystalline form or as a highly concentrated resin. The crystals or resin are dissolved in vegetable oil, a cover of nitrogen being used to exclude air and an antioxidant, mostly hydroquinone, used for stabilization, although vitamin D is usually more stable than vitamin A.

From these different sources concentrates of specified potency are at the disposal of margarine manufacturers. They are mostly prepared by special manufacturers, although some margarine manufacturers prepare and refine their own requirements in the most suitable concentration. Those who draw supplies from outside often find it convenient to receive the concentrate in containers holding the right amount for one charge of fat-blend or one churning of margarine to avoid too much handling and portioning out. For the fat-charge for one ton margarine or for one ton margarine in a churn, which should when finished show a potency of 20 i.u.p.g. A and 1 i.u.p.g. D, an addition of 220 g concentrate containing 100,000 units A and 5000 units D per g is required, as 10 per cent extra should be allowed for losses during mixing and processing. To distribute such a small volume uniformly in the large bulk requires great care, and aeration must be avoided. Many manufacturers prefer therefore to use a more dilute product or to add the high-potency concentrate first to 10–15 kg blend and mix this carefully into the bulk. If the concentrate is added to the bulk just before the artificial colouring, which is also used in small quantities, the visible even distribution of the latter serves as an indication of the dispersion of the vitamin concentrate.

Commercial concentrates containing vitamin A and colour, or synthetic A as palmitate or acetate together with ergo-calciferol D_2 and approved dyes for margarine, are on the market, but these combined products do not permit the flexibility in varying potencies and colour tints as required in some countries. Many manufacturers prefer therefore to use the preparations separately. There is also evidence that some of the colouring materials used for margarine in some countries affect the stability of vitamin A when present in the rather strong concentration of the pre-mixed ingredients, whereas the effect is not noticeable in the concentration in the margarine.

Of high-potency preparations which have found wide use in the margarine industry may be mentioned the products from *Hoffmann-La Roche Inc.*, U.S.A., which are made from synthetic vitamin A acetate or palmitate, standardized with vegetable oil to a potency of one million United States units per g. *Sherwin Chemicals Inc.*, U.S.A., make preparations containing vitamin A, ergo-calciferol D_2, colour and sometimes other ingredients, or just synthetic vitamin A as acetate or palmitate plus colour. *Distillation Products Industries*, Rochester, U.S.A., the first to prepare molecularly distilled vitamin A, sell under the brand Myvapack vitamin A preparations from the palmitate or acetate of potencies from 1·6 million U.S.P. units made by their own synthesis. *Merck & Co. Inc.* sell vitamin A acetate in vegetable oil of 200,000–400,000 u.p.g. strength. In Britain most margarine is now vitaminized with the concentrates from *Advita Ltd.*, London, which are synthetic vitamin A acetate or palmitate, dissolved in edible vegetable oil to a potency of 100,000–140,000 i.u.p.g. and containing ergo-calciferol in such a ratio that the margarine will contain the statutory number and ratio of units of vitamins A and D.

The susceptibility of the vitamins, particularly A, to lose potency gradually by oxidation makes it necessary for the margarine manufacturer to avoid as far as possible to expose the product during the processing to strong daylight and mixing in of air. Vitamin A is a highly unsaturated product containing four double-bonds in the side chain and its oxidation is accelerated by the presence in the fat-blend for margarine of radicals of highly unsaturated fatty acids such as linolenic and more unsaturated acids. Hence soyabean oil and marine animal oils, unless their unsaturation is adequately reduced by hydrogenation, cause a more rapid falling off of vitamin potency than do such fats and oils as coconut oil, groundnut oil, sunflower oil, etc. and hydrogenated fats of iodine value below 65–70. Many oils and fats lose their original content of antioxidants during refining, and initial oxidation of the oils soon affects the vitamins. The question of restoring the antioxidants or adding others will be dealt with in a later chapter; in the meantime it should be mentioned, that margarine made with milk as the aqueous phase, or to which slightly hydrolized casein or sodium caseinate has been added, retains the vitamin potency better than when made with water, probably because the sulphydryl groups in the milk protein have some antioxidant effect.

The natural plant pigment carotene is closely related to vitamin A in chemical composition, and when ingested by humans or animals is converted in the liver into vitamin A. Carotene is found in three isomeric forms, α-, β- and γ-carotene, of which the β-isomer is the most potent as regards conversion into vitamin A. For many years the biological activity of 0·6 microgram of a standard sample of pure β-carotene was the international unit for vitamin A, but recently the pure synthetic vitamin A has been adopted as a basis for standards. Mixed but predominantly β-carotene can be obtained in strong concentration from various natural sources such as carrots, lucerne, palm oil, etc. (see page 107), by drying and selective solvent extraction, followed by partial purification. The chemically pure product would be too expensive for industrial use to fortify margarine with vitamin A potency, but the concentrated carotene extract dissolved in oil as a dark orange-red liquid of a potency of 10,000–20,000 i.u.p.g. vitamin A, equivalent to 6,000–12,000 microgram β-carotene per g, is at times used as a source of vitamin A potency for margarine where for dietary (vegetarians) or ritual (orthodox Jews and Hindus) reasons the use of animal products such as liver oil derivatives is excluded. It is, however, not possible to give the margarine a higher potency than 15–16 i.u.p.g. as it would be too dark in colour. Furthermore, as the potency is due to carotene, and this for humans is only equivalent to about one third of the biological potency of vitamin A proper, the actual biological potency of such carotene margarines is rarely more than 5–6 units vitamin A per g. There is no objection to the use of ergo-calciferol D_2 as source of vitamin D, as it is a vegetable product.

whereas chole-calciferol D_3 may be from animal sources. What the position is with synthetic vitamin A is uncertain, but one of the compounds, citral, from which it can be built up, is derived from vegetable sources.

The same precautions must be adopted with margarine vitaminized with carotene as with that for which preformed vitamin A is used, as carotene is even more prone to loss by oxidation. In the complexes in which it is found in nature it is quite stable, but having once been removed and extracted it is very susceptible.

Vitamin potency can only be checked and controlled by special analytical tests, sensory tests are useless. This question will be dealt with under Process Control.

8. ANTIOXIDANTS

The observation that most natural oils and fats, especially vegetable oils, contain minute fractions of some substances, which retard the onset of the kind of deterioration called oxidative rancidity, led to an intensive study of these "antioxidants", sometimes termed "inhibitols", and it was found that they generally contained tocopherols in small amounts, 0·005–0·1 per cent calculated on the fat; wheat germ oil is exceptionally rich with 0·4–0·5 per cent. They are present in the unsaponifiable fraction of the oils and are identical with the fat-soluble vitamin E; they are phenolic compounds with a long lipophilic side-chain and are found in three isomeric forms, α-, β-, and γ-tocopherol, of which α and γ are the most common, γ being the most effective of them. Inhibitols contain other compounds, but little is known at present of their composition, with few exceptions, such as the sesamol of sesame oil and gossypol of cottonseed oil.

Oxidative deterioration is only one form of fat-spoilage, covered by the term "rancidity". Although several theories have been advanced as to the chemical mechanism involved in the oxidation of fats, they all provide for the formation of an initial stage of peroxides at the double bonds or hydroperoxides arising from addition of oxygen at the labile groups near ethylenic linkages, according to the temperature. This initial stage can be assessed by the "peroxide" value, for example by tests proposed by Lea [124] [125] or by Wheeler [126]. This is important because in this way an indication of proneness to oxidative rancidity in fats can be obtained by accelerated tests. The peroxides do not cause the rancid taste and smell, but change by progressive oxidation into unpleasant tasting oxy-products which cause the spoilage, variously named "oiliness", "tallowiness" etc. Light and very small traces of metals such as copper and iron catalyse this kind of rancidity.

Oxidation is also involved in another kind of rancidity, the so-called ketonic rancidity, which affects fats with saturated acyl groups with 14 or less carbon atoms, such as found for example in coconut and palmkernel oils. The degradation is via beta-oxidation to a keto-acid, loss of carbondioxide from this and formation of a methyl ketone of lower carbon number;

these methyl ketones have a very nauseous flavour. In the presence of water, as is the case with margarine, hydrolysis of the keto-acid also takes place which similarly leads to the formation of malodorous products. Ketonic rancidity can be assessed by the Taüfel and Thaler test [127].

Oxidative changes with aldehyde formation is probably also involved in the deterioration shown some time after deodorization of some oils and fats containing linolenic acid groups or some of their hydrogenation products. This kind of rancidity is often called "reversion", but does not seem to have much resemblance to pre-deodorization flavour. It is not as marked in milk margarines as in dry shortenings.

Another test which is frequently used to measure incipient rancidity is the Kreis test [128] which is indicative particularly of the oxidative rancidity caused by the formation of epihydrin aldehyde.

Hydrolytic rancidity is the result of hydrolysis of glycerides with formation of free fatty acids. As the fats and oils are usually sterile and free from active enzymes this rancidity is mostly caused by lipolytic micro-organisms, particularly yeasts and moulds which gain access to the margarine during processing Although all fats are susceptible to this kind of rancidity,when a trace of moisture is present, it is particularly noticeable in the fats which contain acyl groups of 14 or fewer carbon atoms as these free fatty acids have very pronounced and unpleasant flavour, the stronger the lower the molecular value and the higher the solubility in water. The higher fatty acids such as palmitic, stearic and oleic are practically flavourless. It is therefore specially butter and margarine containing coconut oil, palmkernel oil and babassu oil that show this kind of rancidity, which is measured by the free fatty acid content.

As the risk of hydrolytic rancidity can largely be eliminated by efficient control of manufacture the principal danger of spoilage is the rancidity in which oxidation plays a part, and the subject of antioxidants has therefore been energetically studied, particularly in U.S.A., partly to ascertain the nature, composition and modus operandi of the natural substances, partly to investigate whether analogous compounds of different origin, or chemicals with similar functional groups, can be employed in practice with similar effect on prevention of food spoilage.

The problem is rather involved because some of the antioxidants, for example tocopherols, are present as natural constituents in the raw materials, some may be the same compounds but isolated from their original surroundings and made available for incorporation in fats poor in antioxidants; others again are food constituents, but not always derived from food, for example citric, tartaric, some phosphoric acids and ascorbic acid. Finally, some are manufactured chemicals, such as gallates, thiodipropionate, butylated hydroxyanisole, etc. Where, as at present in Britain, any added substance capable of retarding deterioration of food—with few exceptions—is classified as a preservative and therefore prohibited, the manufacturer of edible fats can take only very limited advantage of the progress made in the elucidation of the functions of antioxidants; in U.S.A. and some other countries lists of permitted antioxidants are drawn up from time to time, when their physiological effect and possible toxicity has been studied.

The problem of antioxidants is further complicated by the facts, that some of them are rather specific and may be effective in one fat, but not in another, that they may have an optimum concentration of activity which varies with the fats, that they may be effective in dry fats, but not in complex systems such as butter and margarine, that they may vary in the way in which the effect persists or "carries through" in food products for which the fat or margarine is used, for example in cakes and biscuits, and that a suitable "synergist" is often required to get the best results. By synergist is meant a substance which itself may or may not be an antioxidant, but by its presence in a certain proportion enhances the effect of another to a greater extent than would be expected from a summation of the two individual effects. Some antioxidants act by interfering with the chain reaction of auto-oxidation; these are principally the tocopherols and other phenolic type antioxidants; they are synergized by some acidic substance such as citric, phosphoric, ascorbic acid, etc., which either directly enhance the activity of the phenols or, if traces of metals are present, immobilize these and thus prevent their pro-oxidant function.

Owing to the complexity of the problem it is in many cases difficult to predict which antioxidant will be the most effective. A fat may already contain sufficient tocopherol so that an addition of, for example, 0·01 per cent citric acid will give optimum effect, whereas an addition of both tocopherol and citric acid will be less effective. Explorative tests are therefore frequently necessary, unless processes and materials are highly standardized.

Antioxidants can play an important part in the preservation of food. For fats and fatty foods, as well as for fat-soluble vitamins, some of the most important so far suggested are the following. It should be remembered that their use is not permitted everywhere.

Tocopherols are present in animal fats and the coconut oil group in very small amounts, 0·002–0·003 per cent, but in crude liquid oils in much higher proportions, to some extent according to their unsaturation; for example, groundnut oil and sesame oil about 0·05–0·07 per cent, cottonseed oil 0·1 per cent, soyabean oil 0·14 per cent. Some is removed in the refining process, particularly by steam distillation in deodorization, and from this distillate a tocopherol concentrate is made by molecular distillation. This purified concentrate is sometimes used as antioxidant for vitamin A concentrate, but not to any practical extent in edible oil. The residual tocopherol in the deodorized oils is usually present in such concentration, 0·04–0·07 per cent, that the addition of an acid synergist, such as 0·005–0·01 per cent citric acid, enhances the tocopherol effect and improves considerably the stability of the refined oil. Ascorbic acid and ascorbyl palmitate have also been used as synergists with tocopherol, but seem uncertain in effect in margarine.

Gum guaiac and nordihydroguaiaretic acid are both plant products permitted in U.S.A. as antioxidants in proportions of 0·1 per cent and 0·01 per cent respectively. The active substance is phenolic and these materials are employed with 0·005 per cent citric or phosphoric acid as synergist principally in animal fats. They are of rather strong taste which does not seem to blend well with that of margarine.

Vegetable phosphatides of the soyabean lecithin type are often found to have antioxidant properties, particularly when present together with tocopherol. It has been suggested that the acidic phosphoric acid group in the lecithin synergizes the tocopherol. There is probably also some tocopherol activity in the lecithin itself, as the commercial product usually contains 30–40 per cent soyabean oil and has not been strongly steam deodorized; there might therefore be about 0·05 per cent tocopherol present, which could explain why vegetable lecithin itself is often found to be an antioxidant, provided its lipids have not been oxidized by unsuitable storage of the seed, faulty processing during extraction and by prolonged storage, in which case it acts, as do all oxidized fats, as a pro-oxidant.

Other "natural" substances with antioxidant activity are wheatgerm oil with its high tocopherol content and sesame oil with sesamol and sesamolin. These oils have excellent keeping quality and impart some of it to other fats when used in mixtures.

As already mentioned the casein of milk has antioxidant effect both in fat and in margarine. The same is the case with hydrolized casein and with sodium caseinate. This is ascribed to the presence of sulphydryl groups in the protein and its derivatives. A number of sulphur compounds have been found to be antioxidants in certain foods, for example dialkyl-dithiocarbamate in cream and butter at 0·02 per cent [129].

Natural tannins are good antioxidants for many foods, but not suitable for fats because of their insolubility and their colour reaction with traces of iron. Esters of tannic acid, however, are moderately soluble in fat and have been recommended as antioxidants in the form of ethyl-, propyl- and higher esters; they have a rather bitter taste which even in the recommended small proportion of 0·01 per cent is at times noticeable. Their effect is enhanced by an acid synergist such as 0·005 per cent citric or phosphoric acid, and is particularly striking in butter fat and milk powder. They have also been found effective in margarine with acid serum, but their taste is generally against their use in that product; possibly the salt enhances their flavour. Propyl gallate is on the permitted list in U.S.A. and Canada, and recommendations have been made, that it should be permitted in Britain to the extent of 0·01 per cent.

A number of chemicals of phenolic type or with groupings similar to those active in the natural antioxidants have been tested and some have been found effective. Of those permitted in certain countries may be mentioned isopropylcitrate (up to 0·02 per cent in margarine in U.S.A.) stearylcitrate (up to 0·15 per cent in margarine in U.S.A.), butylated hydroxyanisole (0·02 per cent in U.S.A. and also recommended for permission in Britain), thiodipropionic acid (0·01 per cent in U.S.A.), the dilauryl or distearyl salt of this acid (0·09 per cent in U.S.A.) as well as various combinations of these with others and with synergists.

A very effective antioxidant in fats, both by itself and with synergists, is hydroquinone, which however is not commendable in foods even in the small effective proportion of 0·01 per cent, and in some countries it is definitely prohibited. It is also very effective in oil-solutions of vitamins A and D, and is used for that purpose in medical and test preparations.

It has been claimed in Germany [130] that citraconic acid is a very good antioxidant for fats in the proportion of 0·03–0·045 per cent and is better than gallate in margarine, as the flavour is satisfactory and it is physiologically unobjectionable.

The effectiveness of added antioxidants in margarine is rather complicated, compared with their use in dry fats such as lard and shortenings. The presence of some natural antioxidants in the fat and the milk, the tocopherols and inhibitols carried through the refining process, the sulphur compounds from the milk as well as the lactic and citric acids, and often the added lecithin, provide a complex system of substances which may mask the effect of any of the additions, which have been made more specifically as antioxidants. There may already be present the optimal amounts, and further addition may have none, or perhaps even unbalancing effects. Another condition frequently plays an important part, namely the pH value of the serum. While an acid serum in many cases has a synergistic effect on fat-soluble antioxidants such as tocopherol, lecithin, etc., it has in the presence of salt in a concentration in the serum of 6–20 per cent, which are quite common concentrations, often the opposite effect particularly if there is even a very small proportion of highly unsaturated fatty acid radicals in the fat, as is the case with some vitamin concentrates from liver oils and some oils containing linolenic and arachidonic acid radicals, as well as with insufficiently hydrogenated marine animal oils. It is probably caused by the salt forming some oxy-acid compound. As a remedy for this risk many margarine manufacturers raise the pH of the serum to 5·8–6·4 by adding soda or, where boric preservative is permitted, by using a borax-boric acid mixture with same effect. (See pages 94 and 106.) It is therefore erroneous to attribute direct antioxidant effect to the carbonate or borax; the same result would be obtained by using unripened milk.

Air content of margarine likewise plays a part in the keeping quality and in assessing the effect of antioxidants. Fat exposed to air usually holds in solution 6–8 per cent of air by volume. The vacuum deodorized fats and oils are practically free from air, but during storage and preparation, during processing and cooling some air is dissolved in the fat, and during churning and kneading some air is worked into the margarine and is present in a dispersed form, visible as air bubbles under the microscope. This may be from 8–12 per cent by volume, and even if the final kneading operation is under vacuum there is often 3–5 per cent dispersed air present. These very fine films and bubbles of dispersed air as well as the dissolved air offer favourable conditions for oxidation, but for the presence of natural or added antioxidant and, particularly, the relatively low temperature of margarines. Below 20–25°C oxidation proceeds very slowly unless oxidation catalysts, such as oxidized fats, small traces of copper, manganese or iron, or highly unsaturated fatty acid radicals, are present. Oxidation does, of course, occur, as evidenced by a slow gradual increase in the peroxide content of the fat, but normally it takes some weeks before it degrades the margarine to the extent of spoiling its flavour. A humid atmosphere also accelerates deterioration, particularly the development of ketonic and hydrolytic rancidities; hence a visibly dry, well emulsified margarine, close packing and dry storage are important points.

The accelerated tests for assessing the susceptibility of a fat-mixture to auto-oxidation or the potential effect of added antioxidants, which have proved so useful in practice for fats and shortenings, are not applicable to margarine. The Swift test [131] measures in its various modifications the development of sensory and peroxide rancidity by aeration of samples at 98°C under standardized conditions. The Schaal test [132] provides for incubation of the sample at 60°C and measures the time taken for development of rancid odour and the peroxides formed at that stage. Margarine, however, disintegrates at much lower temperatures, and no satisfactory accelerated test, that can be completed in a few hours or a few days, is available. Some indication of the stability can be had from storing samples of margarine at, for example, 25°C and following the peroxide development in the fat by weekly test and correlating this with flavour, but with good margarines 2–3 weeks may pass before clear results are obtained, if at all, as peroxides may have changed into more stable oxidation products of more rancid flavour, but lower peroxide value. Before therefore deciding whether an added antioxidant is of practical value for margarine extensive time-consuming standardized tests are advisable. And the legal and physiological aspect should be considered first.

The practical application of antioxidants to preservation of fatty foods has been more extensive in U.S.A. than in other countries, and particularly in connection with preservation of lard and milk powders. Commercial products are sold under trade brands and often consist of mixtures; for example, one brand contains propyl gallate, citric acid, lecithin and maize germ oil, which is rich in tocopherol; another brand contains in addition butylated hydroxyanisole. The literature on antioxidants is now very extensive; several valuable reviews have been published in the technical press [133] [134] [135] [136].

9. EMULSION STABILIZERS AND EMULSIONS

The principal raw materials for margarine, the fat-blend or fatty phase and the milk or aqueous phase, are intimately mixed by emulsification or churning. The minor materials or ingredients are, according to their solubility, often dissolved in these phases before emulsification, particularly when continuous processes are used. As mentioned on page 2 the earliest margarine was churned by mixing the fat with a high proportion of milk and water, about 60 per cent in the emulsion, so as to produce a creamy liquid similar to cream for butter making. In course of time the proportion of aqueous phase was reduced and in modern processes it is usually just sufficient to give the final margarine the correct moisture content, in most countries 15–16 per cent. The emulsion is practically always made with the two phases in fluid form; there are however a few factories where the solid fat-blend is plasticized and the aqueous phase is worked into and dispersed in the plastic mass.

Oils and water are immiscible liquids, and although by mechanical vigorous agitation they can be emulsified, the emulsion separates rapidly on cessation of agitation, if the phases are in the proportions used in margarine, unless one or more other substances are present to stabilize the emulsion. Even the rapid solidification, as is the case in the manufacture of margarine, which places a restraint on the separation by immobilizing the fatty phase, does not prevent the partial coalescence and leakage of the water phase, which gives the product a wet appearance and makes it very prone to deterioration.

When oils and water are mixed two types of emulsion are possible. In the oil-in-water type (O/W) the oil is dispersed in the water as droplets, i.e., the oil is the disperse, discontinuous or internal phase, surrounded by the water as the continuous or external phase. In the water-in-oil type (W/O) the arrangement is the opposite. The pattern for emulsification of margarine was originally the process of butter making, in which cream with 20–40 per cent fat as an O/W type of emulsion is shaken or agitated in a churn until the microscopical fat-globules agglomerate, first into granules, later into more cohesive lumps which represent a predominantly opposite type of solid emulsion, while the bulk of the aqueous phase, the buttermilk, segregates and is drained off. This "inversion" of the emulsion changes the material from a viscous liquid cream to a fatty solid butter. The inversion takes place at a temperature well below the melting point of the fat (30–32°C), usually at 12–16°C, with partial crystallization and solidification of the higher-melting glycerides.

Various theories have been advanced to explain this phase inversion. The fat-globules in the cream are coated with a thin interfacial layer, sometimes called the mucous membrane, which is a protein-lecithin complex and is largely responsible for stabilizing the O/W cream emulsion. Some of this is shed in the churning process and has been recovered from the buttermilk; it has been found capable of stabilizing other O/W emulsions. STORCH's [137] theory of cream inversion into butter suggested that abrasion of the interfacial membrane during the agitation of the cream in the churn exposes the fat-globules to agglomeration and by adhesion makes them form larger and larger grains which separate from most of the aqueous phase, but occlude some of this and of the original emulsion system as an internal phase in the external fatty phase. Enough of the stabilizing substance is present in the solid emulsion to ensure a fine dispersion of the moisture in the butter, thereby avoiding, as long as the product is solid, exudation or "weeping" of water droplets, even in the presence of the electrolyte salt which tends to break some emulsions.

The FISCHER-HOOKER theory [138] suggests that a change in the hydration of the colloidal substance in the interfacial layer causes instability of the cream emulsion leading to breaking of these layers and coalescence of the fat.

RAHN [139] in his "foam" theory believes that the violent agitation of the cream in the churn causes a concentration of fat globules in the foam layer thus breaking the homogeneity of the cream emulsion. This accumulation and tight packing of fat-globules leads to a change in the colloidal protein supporting the foam, which then collapses, and further churning causes the agglomeration of the fat-globules to butter. Allied to this theory is the recently patented method of forming butter by blowing carbon dioxide through the cream [140].

Phase inversion in butter making seems, however, to be principally concerned with temperatures as shown by the latest continuous methods. For example, in the Alfa-Laval process cream is concentrated in two stages to a fat content of about 82 per cent, salt, if required, added to this cream which is an O/W emulsion, and the cream passed through a tubular cooler, the transmutator, of special construction, where it is moderately stirred and worked during cooling. When cooled to a temperature of 9–12°C the type of emulsion changes largely to W/O and a continuous stream of this butter in soft plastic form issues from the cooler ready for packing; it hardens up to butter consistency in a few minutes. In this case there is neither foam nor dehydration of colloidal membranes. The cream and the butter have the same chemical composition and the inversion of the phases takes place in that section of the cooler where the temperature is 9–12°C. There is no loss of buttermilk and the dispersion of the internal aqueous phase is very fine and stabilized by the colloidal interfacial material. That the inversion is essentially a temperature question is shown by a still simpler process in which there is no mechanical treatment for the phase inversion. In this process the concentrated cream of 82–84 per cent fat-content is taken from the secondary concentrating centrifuge, which works under slight pressure with complete exclusion of air, as a warm liquid cream and run into containers which are ultimately placed in a cool store. No mechanical working takes place, but when the temperature in storage is below 10–12 C phase inversion occurs gradually and butter is formed.

While the different methods all give butter in which the external phase is butter-fat they differ in the proportion of butter-fat still in the gobular form which is dispersed in pure butter-fat together with serum droplets and air bubbles as internal phases. According to MOHR [141] about 24 per cent of the butter-fat is present as globular fat in ordinary butter against 8–12 per cent in butter made by the continuous Alfa-Laval process. In the butter from concentrated cream, inverted by cooling without mechanical working, samples have been found containing as much as 30–40 per cent globular fat as internal phase, the remaining 45–55 per cent fat being the continuous phase. There are indications that butter with the higher proportions of globular fat shows greater resistance to changes in consistency with slight changes in temperature. The water droplets in butter from concentrated cream are usually in much finer dispersion than in ordinary butter. If all the butter fat were present as the external phase and the water droplets dispersed as finely as is the case in this kind of butter, the sensation on the palate would be that of a greasy and dry product, as the flavour resides principally in the aqueous phase; its extremely fine dispersion in the fat would make it less accessible to the gustatory system, even though the fat melts on the palate. This relationship between flavour and fineness of the emulsion is much more important in connection with margarine, where there is often no globular fat in the internal phase.

Various methods can be used to ascertain the phase system, where this is not immediately obvious. Of those used often in factory practice may be mentioned: (*a*) The Dilution method, in which the emulsion is diluted by adding the external phase; if water or milk is added to an O/W emulsion a thinner emulsion of the same type is formed; if oil is added it floats to the top and forms a separate layer. If the emulsion is W/O, oil will dilute it, whereas added water or milk will form a separate layer at the bottom. (*b*) The Colour Indicator method in which a fat-soluble red dye, usually Sudan I or Sudan III, and a water-soluble dye such as Methylen-blue are used for dyeing the two phases, which can then be distinguished under the microscope. Or a little of the powdery fat-soluble dye is placed as a few spots on the surface of the emulsion; if the emulsion is of the W/O type the dye will dissolve and spread gradually over the whole surface, whereas on the opposite type of emulsion it would just dye a few spots where placed. (*c*) The Electrical Resistance method which measures either the dielectric constant or the resistance in ohms of the emulsion. A W/O emulsion of margarine has a resistance of the order of 10,000–20,000 ohms, according to the electrolyte content of the internal aqueous phase, whereas an O/W emulsion shows usually a resistance of less than 500 ohms.

It is arguable whether butter and margarine can be described truly as emulsions. As long as these products are solids, separation of the phases is largely impeded by the physical state of the fat. If heated above the melting point of the fat separation takes place more or less rapidly according to the temperature, the degree of dispersion and the efficiency of the stabilizer or emulsifying agent. An indication of the proneness to separation is obtained by keeping the product in measuring cylinders at 60°C, or 20–30°C above the melting point of the fat, and note the time and type of separation. Some emulsions will separate in a few minutes, others will take hours.

As already mentioned, the emulsion stabilizer in cream and butter is largely the protein-lecithin complex in the interfacial layer, and the very fine dispersion of water and the rather more fatty type in Alfa-Laval butter may very likely be due to the higher proportion of lecithin in this type of butter, 0·44 per cent, compared with 0·31 per cent in the normal type of butter, as determined by ethanol extraction.

While the churning process in butter manufacture is largely a phase inversion of an existing emulsion, it is in the manufacture of margarine the creation of an emulsion from a homogeneous fat-blend and an aqueous liquid. With the proportions in which these phases are used in margarine the type of emulsion resulting from the churns tends definitely towards a W/O type, but whether some of the opposite type is present, and also the degree of dispersion, depends not only on the process technique, but also to a high degree on the colloidal emulsion stabilizer or emulsifying agent.

As the surface tension of water is greater than that of the fat-blend, the tendency is for the water to be dispersed as globules in the fat when they are stirred together, but owing to the immiscibility of the two phases the emulsion is very unstable. If an emulsifying agent is added, which is preferably wetted by the fat, it lowers the surface tension of the fatty phase and promotes the W/O type. Such an agent contains lipophilic groups in the molecule, such as long-chain fatty acid radicals or condensation products; it is adsorbed in the interfacial layer and the lipophilic groups are orientated towards the fat and enhance the subdivision of the internal aqueous phase, and the film impedes the coalescence of the water droplets.

If the emulsifying agent is preferably wetted by or dissolved in water it lowers the surface tension of this and promotes the O/W type. These agents contain hydrophilic polar groups, OH, HSO_4, COONa, etc. and are in the interfacial layer orientated towards the water and will tend to form the type of emulsion represented by cream, or if a large excess of fatty phase is present it may cause a dispersion of O/W emulsion in the aqueous phase which again is dispersed in the bulk of the fat.

As examples may be mentioned that sodium soap, soluble in water, promotes the O/W type; calcium soap, soluble in oil, the W/O type of emulsion.

Some emulsifying agents have both hydrophilic and lipophilic groupings and are widely used. According to the relative efficiencies of these groupings they perform the various functions of emulsion stabilization, dispersion, moisture retention, and anti-spattering when the water is boiled off in frying. So-called "balanced" agents with a certain effect equilibrium between the groupings perform all the functions, otherwise several agents are used together. The conception of "balanced emulsifiers", which are mostly synthetic, was particularly developed in U.S.A. by A. K. Epstein, B. R. Harris and Emulsol Corporation, who have taken out a number of patents on this subject [142] [143].

A very large number of emulsifying agents have been proposed from time to time, and many have been patented. Of those which have gained an established place in the manufacture of margarine the following may be mentioned.

Egg yolk, the use of which for "browning" is dealt with on page 111, was one of the first to be employed, and it is still widely used. In the liquid or vacuum-condensed form it is very effective as dispersing agent, moisture retainer and anti-spatterer when used in the proportion of 0·25–1 per cent, as liquid. When used in margarine with milk serum of pH above 5·5 there is often evidence that it helps with certain churning techniques to disperse some of the fat as an O/W emulsion which is then held with the rest of the milk serum as an internal phase in the external phase of the bulk of the fat. This is due to the dual nature of egg yolk, in which there is both strong hydrophilic and lipophilic material, and it improves also the consistency of the margarine; the re-dissolved dehydrated egg yolk is less effective for this purpose. Egg yolk imparts to margarine fat, when all the water has been boiled away in frying, the golden brownish tint, which is characteristic of butter and is due to the lecithin content, and the very fine water dispersion which it effects in the margarine causes the moisture to be released during frying in numerous minute bubbles, giving a gentle ebullition with a fine foam, thereby preventing spattering, which results from rather explosive release of vapour from larger bubbles. The presence of salt in the margarine enhances the anti-spattering effect. The coagulated milk solids and other proteinaceous substances in the minute bubbles will form a fine powdery sediment which the brisk regular ebullition prevents from burning on to the bottom of the pan. The drawback of egg yolk is its rather perishable nature, as it is difficult to get it sterile, and it provides good nutriment for proteolytic micro-organisms.

Lecithin, in practice nearly always vegetable lecithin and mostly soyabean phosphatides (see p. 113) is similar in its function to egg yolk, but not quite so effective. It is very widely used in the margarine industry because of its lower price and better keeping quality. Although it is hydrated by water its affinity for the aqueous phase is less than that of egg yolk, which contains colloidal protein, but in the phophoric acid esters with choline and colamine it has polar groups which in the interface are orientated towards the milk serum or aqueous phase, although it is more strongly orientated towards the fatty phase because of the lipophilic groups provided by the two long fatty acid chains in the molecule. Its good dispersing power in the W/O emulsion makes it an effective ingredient for steady ebullition and foaming during frying and it has like egg yolk a good browning effect on the hot fat and prevents burning on of the sediment. Usually 0·2–0·25 per cent is added; the effect is better with a slightly higher proportion, but above 0·4 per cent its characteristic taste begins to be noticeable. Better results are obtained with milk margarines than with water margarines. It does not itself contribute to the frying sediment as it is soluble in fat. Vegetable lecithin generally contains a few per cent of vegetable sterols, "phytosterol", which through its polar OH group adds to the hydrophilic effect.

Milk is an emulsifying agent, the colloidal proteins being the active substances. In the unripened form it promotes the O/W type and by special churning technique emulsions of 85 per cent fat-blend in skim milk can be made [144]; these are, however, unstable when the fat crystallizes and phase invertion takes place because of the high proportion of fat. Generally the tendency with the standard churning process is to form an W/O or a mixed type emulsion when there is more than 50 per cent fat-blend. With ripened milk of pH 4·3–4·5, where most of the protein is coagulated, the stabilizing effect is merely fair and only thickening of the mixture by cooling or solidification prevents rapid separation, particularly if salt is present. Even intense fine mechanical dispersion of the aqueous phase immediately prior to solidification or during this does not always prevent slight exudation of moisture after some time, unless some further emulsifying agent is used. The higher the pH the better the dispersion and the resistance to separation of the emulsion, and many manufacturers for this reason, and for reasons already mentioned (page 94) prefer to reduce the acidity of the aqueous phase to pH 6–6·6 by adding, for example, some borax or other alkali.

A special method sometimes used to obtain the benefit of ripened milk and the full milk-solid content and still make use of the stabilizing and dispersing effect of the colloidal milk casein consists in the use of sodium caseinate. In this method the aqueous phase is a mixture of equal parts of ripened skim milk and water; to this is added a viscous casein cream made by coagulating the curd from ripened skim milk, removing from it most of the whey by draining, dissolving the curd in a sodium hydroxide solution to a solids content of about 30 per cent and of slight alkalinity, neutralizing the viscous liquid with ripened milk or lactic acid, and finally mixing this neutral product with an equal weight of edible oil, such as groundnut oil. Of this artificial cream sufficient is added to the margarine to introduce 0·3–0·5 per cent milk solids additional to those from the milk and water mixture used as aqueous phase. It is a very efficient emulsifier with moisture retaining and anti-spattering properties.

Soap is not normally used as emulsifying agent for household margarine, as its taste is noticeable when as little as 0·1–0·2 per cent is present. In certain special qualities, made for use in confectionery, up to 0·3 per cent of sodium soap of high-molecular fatty acids, palmitic, stearic and arachidic, or 0·1 per cent calcium soap is sometimes used to give special stabilizing effect, the sodium soap for O/W, the calcium soap for W/O emulsions.

Of the many glyceride derivatives, which have been made for use as W/O emulsion stabilizers and water dispersing agents, the first to find application in the manufacture of margarine was E. SCHOU's Palsgaard Emulsion Oil, in the industry known as P.E.O., made by Emulsion A./S., Denmark. It was introduced in 1922 and although modified and improved forms of it are now preferred for margarine, it is still used in that industry and for many purposes as an W/O stabilizer. It is a viscous oil made by polymerizing and oxidizing a semi-drying vegetable oil, mostly soyabean oil, at about 250°C until it thickens, cooling to about 100°C and diluting with about 12 parts edible soyabean oil until the mixture has certain viscosity characteristics [145].

0·3–0·5 per cent of P.E.O. dissolved in the fat-blend strongly reduces the interfacial tension between the fatty and aqueous phases, and being fat-soluble effects a very fine dispersion of water or milk in the fat; probably the presence of some polar groups in the polymerized molecules enhances this effect. When P.E.O. is used as emulsifying agent for margarine, the speed of agitation and the control of temperature during churning is not so critical as without, and the liquid emulsion shows much greater stability than fat-milk-water emulsions without P.E.O., which also has good anti-spattering properties, but does not "brown" well and gives no sediment by itself. However, since the original P.E.O. was introduced, improved modifications for margarine have been developed, partly to enhance the "browning" effect by higher dispersing action on milk solids, partly to increase water retention in the margarine through strengthening the interfacial effect by using fats or fatty acids of high melting point, about 54°C, in the structure of the emulsion stabilizer molecule. The products of this type are designated P.A.F. (Palsgaard Adsorption Fat) and are esters of polyglycerol with high-melting fatty acids or mixtures of mono and diglycerides of these acids. Reference to mono- and diglyceride emulsifiers will be made below.

Other emulsifying agents of the polymerization type have become available, such as for example the Homodan O products of *Grindstedvaerket*, Denmark, which consist of polymerized and oxidized fatty acids esterified with glycerol so that the product contains at least one free OH group [146].

Another type of emulsifying agent which is much used in margarine, principally for moisture dispersion and retention, is that often known in the trade as glyceryl-monostearate, which is a mono and diglyceride of long-chain fatty acids, or fatty acid esters of di- or polyglycerol with one or more free OH groups. The presence of both lipophilic and hydrophilic groups makes them useful for reducing the interfacial tension and good promoters of W/O emulsions. The commercial so-called glyceryl monostearate contains usually about 40 per cent monoglyceride, 40 per cent diglyceride and 20 per cent triglyceride, and the fatty acids may be a mixture of several long-chain acids, mostly saturated. As the monoglyceride is the most active emulsifying agent in the mixture, the manufacturing process can be regulated so that a high concentration of monoglyceride, 80 per cent or more, is obtained, either by interesterification of fats and glycerine or esterification of fatty acids and glycerine. Both processes are promoted by 0·1–0·2 per cent of a catalyst such as sodium hydroxide; if the emulsifying agent is intended for use in margarine the soap formed by the alkali must be removed by neutralization with mineral acid and the salt filtered off. Fatty acids liberated from the soap may be ignored or can be distilled off if the product is deodorized. Margarine manufacturers, who make their own monoglyceride products, often use the same fat-mixture as in margarine, excluding the lauric and myristic acid group of fats, or they use a fairly highly hydrogenated fat as basis for the emulsifier. The proportion of monoglyceride product used in margarine is generally of the order of 0·2 per cent based on 60 per cent mono content. Although patents were granted to Harris in 1933 in U.S.A. for the use of monoglyceride as emulsifying agents [147], this practice seems to have been fairly widespread in the European industry then.

The so-called "balanced" emulsifying agents, described in the many American patents already referred to on page 130, are particularly suggested as anti-spattering agents; this effect depends on a certain balance of long-chain lipophilic groups and polar hydrophilic groups, the balance being ascertained by the usual standardized empirical test for spattering of margarine during frying, namely by observing the size and number, sometimes the weight, of grease spots collected on filter paper placed for catching the droplets ejected from the frying fat. If few or no spots are found the agent is judged to be "balanced", whereas an unbalanced product shows many spots. Some of this type of emulsifier are balanced within the same molecule, such as fatty acid esters with sucrose or with phosphoric acid esters, sulphur compounds, nitrogenous hydrophilic groups, or cholesterol sulphoacetate, sulphonated monostearine sodium salt, phosphoric acid ester of monostearyl glycerol, etc. Other balanced emulsifiers contain two substances, for example monostearin sulphoacetate salt and glycerol monostearin, the former being essentially anti-spatterer, the latter a hydrophilic fatty substance as moisture retainer. Of these many agents the one that has found most use in margarine factories is probably that known in the trade as Emargol, a mixture of a mono-diglyceride and a monostearin sulphoacetate. This is similar in composition to the European product Pancol.

These balanced emulsifiers are only slightly soluble in the oil and water phases, are colloidal or semi-colloidally dispersible in the phases, but concentrate in the interface and owe their efficiency to their being orientated towards both phases. They are non-volatile and remain in the fat during frying, but do not contribute any browning or sediment. The proportion is normally 0·1–0·25 per cent. Their activity is unaffected by mildly acid conditions, as for example ripened milk.

In recent years a very large number of emulsifying agents for margarine and other edible fatty products such as special shortenings, mayonnaise, ice cream, bakery emulsions, bread improvers etc. have been patented and recommended; they are usually supplied under a trade name, but are mostly variants or combinations of the types described. For example, polymerized oxidized oil of the P.E.O. type is esterified with fatty acids [148]; glycerol is polymerized and esterified with fatty acids so that the esters have at least one free OH group and at least one polymerized fatty acid radical [149]. A. Herlow has patented the production and use of polymerized oil and monoglyceride, in which the monoglyceride contains higher melting fatty acid radicals, so that the combined product has a melting point of 20–60 C which gives a solid interface, that is claimed to enhance the stability of the emulsion [150]. These and other combinations of monoglycerides and polymerized products, precombined or added separately to the emulsion, often contain fairly high proportions of free fatty acids, 2–10 per cent, soap, 1–6 per cent, from the catalyst action, and unsaponifiable matter, up to 7 per cent. Where they are used in margarine, products low in these substances should be selected; soap in particular introduces a risk of sharp taste and attack on the margarine fat by inducing hydrolysis. A number of varieties of products from *Emulsion A./S.*, Denmark, and Homodan products from *Grindstedvaerket*, Denmark, fall into this category.

A monoglyceride type of stabilizer which is much used in margarine is the Admul M.D.G. brand of *Advita Ltd.*, London; it contains less than 2 per cent soap and 0·4 per cent free fatty acid; the melting point is 46–48°C and it is therefore of the type that gives a solid interface. Other monoglyceride type products are, for example, the Romuls brands of *M.R. Chemicals*, London, and the Tegemuls of *Th. Goldschmidt A.G.*, Essen, Germany. The "balanced" agents made under the Epstein and Harris patents are specially favoured in America, where they are made by the *Emulsol Corporation*, Chicago.

If the margarine manufacturer wishes to use an emulsifying agent—and they are very useful to obtain the different effects resulting from a good emulsion—he should try out which of the many preparations, or which combination, suits his conditions best. Much depends on the conditions and preparation of raw materials and other ingredients. The presence in the fat-blend of glycerides containing linoleic and linolenic acid radicals seems to increase the effect of some emulsifiers, and there are indications that iso-acids of some hydrogenated fats have a similar tendency. Some are less effective with fully ripened milk, others are not affected by mild acidity; some are inert towards variations in salt content, others somewhat sensitive. The type of chemical preservative and of acid antioxidant synergist may affect results. With the widely varying conditions of composition and manufacture from factory to factory it is therefore necessary to acquire information and experience by rather empirical methods.

Certain exploratory tests are usually made; for example, liquid oil and water with the customary addition of the agent, 0·1–0·5 per cent, are intimately mixed under standardized conditions, the mixture poured into a tall cylindrical glass and kept at a suitable and constant temperature, 20–30°C; the time taken for separation of the fatty phase, or some similar observation, may be a measure of the efficiency of stabilization by the agent. The type of oil may, as mentioned, affect the result slightly and some manufacturers test the agent in a sample of the actual fat-blend, in which case the test should be done at higher temperature, 40–60°C (see page 129). Other manufacturers, in view of the combined influence of all ingredients, test the actual margarine emulsion in the same way, but here the conditions of churning, temperature, system of mixing, speed and construction of agitators or paddles may play a part unconnected with the emulsifying agent. Microscopical study of the dispersion is useful, but is most informative on the finished margarine, as different agents have different resistance to the effect of compression or shearing-blending during the plasticizing of the product and to the possible disruptive effect of fat-crystallization during solidification. Some stabilizer manufacturers adjust the type of their product to suit the effect of the working of the solidified emulsion during the kneading and plasticizing processes. Where frying and anti-spattering effect is to be assessed a test of the kind mentioned on page 134 should be done.

The object of using emulsifying agents is primarily to obtain in margarine the effect which in butter is largely obtained by the protein-lecithin complex and other colloidal milk-protein complexes as emulsion stabilizers. But, as mentioned on page 127, the formation of the butter emulsion is accompanied by a partial crystallization of the glycerides, and it has been found that those which form the external phase have usually a more amorphous character and contain more of the low-melting glycerides than those which are held as globules dispersed with the serum in the external phase. This may not have any effect on the stability of the emulsion, but affects the sensory reaction on the palate. There is a more rapid melting, and therefore a cooling sensation, of the lower-melting external phase, when exposed to the body temperature, and more immediate access to the internal aqueous phase which largely carries the flavour elements. The more satisfying and lasting effect is then given by the internal phase of higher-melting glycerides, which also, but more slowly, melt at body temperature. A patent by *Grindstedvaerket*, Denmark [151] describes a method for producing an emulsion of the type just described for butter. According to this a primary emulsion of the O/W type is made from the aqueous phase and the higher-melting part of the fat-blend in the presence of an emulsifying agent; this primary emulsion is then dispersed in the rest of the fat-blend, which is of lower melting point, but solid at normal temperature. This means producing a double emulsion of the oil-in-water-in-oil type. By sufficiently fine dispersion into the external phase the primary emulsion resolves itself into separate globules of fat with an interfacial separating layer and water globules with a similar layer, both phases being present as discreet particles in the external fatty phase. The two fractions of the fat-blend can also be dispersed separately into the aqueous phase, thus forming two separate internal phases; this aqueous emulsion of high fat percentage is then processed as is margarine by cooling, solidification and kneading, whereby through partial inversion an external phase is formed by the lower-melting fraction of the fat-blend, while the higher-melting fraction and the aqueous phase are dispersed. The amount of fat in the dispersed state varies; for example, the fat percentage in the primary emulsion may be 50–60 per cent; if the concentration is 50 per cent it would mean that about 18–20 per cent of the fat-blend is present as dispersed fat, 80–82 per cent as external phase in the final emulsion. The temperature of the fat forming the primary emulsion should be so high that it is liquid; afterwards the temperature is lowered sufficiently to partly solidify the dispersed fat, while still keeping the fat for the external phase liquid, while the primary emulsion is being dispersed in it. Finally the whole product is solidified, and the finished margarine is stated to give the same sensation on the palate as butter, i.e., rapid melting of the external phase and access to the flavour-carrying aqueous phase and the sustaining effect of the slower melting internal globular fat phase. In addition it is claimed that the consistency and spreading properties of such a margarine are better and more similar to butter than of a margarine made by the conventional emulsification process. As emulsification agents for the primary emulsion the patentee recommends a rather high percentage of lecithin and diglycerol monostearate, about 4 per cent in total on this emulsion, and where the fat percentage in the primary emulsion is high and therefore less fat-blend is left as the final external phase it is recommended to use as stabilizer in the final emulsification process about 0·3 per cent of a mixture of monoglyceride and polymerized oil, calculated on and dissolved in the external phase.

As already mentioned it is not practical or possible to lay down definite rules as to which emulsifying agents, their combinations and proportions will give the best results in all circumstances. A few examples may illustrate what has been found useful in some factories under their local conditions:

1. $\frac{2}{3}$ ripened milk and $\frac{1}{3}$ water as aqueous phase.
   0·4 per cent polymerized fatty acid monoglyceride plus 0·15 per cent lecithin plus 0·25 per cent sodium bicarbonate.
2. $\frac{1}{5}$ ripened milk and $\frac{4}{5}$ water as aqueous phase.
   0·35 per cent lecithin plus 0·1 per cent hard monoglyceride.
3. $\frac{2}{5}$ ripened milk and $\frac{3}{5}$ water as aqueous phase.
   0·13–0·15 per cent lecithin plus 0·17–0·25 per cent hard monoglyceride.
4. $\frac{7}{10}$ ripened milk and $\frac{3}{10}$ water as aqueous phase.
   0·3–0·5 per cent egg yolk plus 0·15 per cent lecithin plus 0·2 per cent monoglyceride.
5. Ripened milk as aqueous phase.
   0·1 per cent lecithin plus 0·4 per cent egg yolk.
6. Water as aqueous phase.
   0·8 per cent egg yolk plus 0·2 per cent polymerized oil (P.E.O.).
7. $\frac{1}{4}$ ripened milk and $\frac{4}{5}$ water as aqueous phase.
   0·4 per cent lecithin plus 0·4 per cent monoglyceride.
8. Water as aqueous phase.
   0·8 per cent monoglyceride.
9. Ripened milk as aqueous phase.
   0·125 per cent monoglyceride plus 0·3 per cent polymerized oil monoglyceride.
10. Water as aqueous phase.
    0·1 per cent polymerized oil (P.E.O.) plus 0·2 per cent lecithin plus 0·35 per cent egg yolk.
11. Ripened milk as aqueous phase.
    0·2 per cent lecithin plus 0·2 per cent balanced Emargol.
12. $\frac{1}{2}$ unripened milk and $\frac{1}{2}$ water as aqueous phase.
    0·2 per cent lecithin plus 0·2 per cent egg yolk.

III. THE PROCESS

Churning and Emulsification

1. GENERAL REMARKS

THE preceding chapters have dealt with the origin and preparation of the two principal raw materials, the fat-blend and the aqueous phase, and with the ingredients. The next step in the process is the mixing in appropriate proportions of these materials by emulsification or churning, the latter term generally being used where the process is carried out batchwise in the type of vessel called the churn, in analogy with butter making.

Some of the physico-chemical principles underlying the emulsification process have been mentioned in the chapter on Emulsion Stabilizers. The ratio of the two phases influences the type of emulsion, which is formed by vigorous mixing and agitating of the materials in liquid form, and in earlier practice when 40–60 per cent of aqueous phase was often used, and frequently in the form of unripened milk, the liquid emulsion was probably in many cases of the cream or O/W type, as sometimes stated in older literature, or a mixture of that type and the W/O type. Solidification, working and kneading effected the inversion of the emulsion type to W/O with possibly a dispersion of some O/W type therein.

In modern practice, the proportion of the aqueous phase is rarely more than is necessary to give the desired final moisture content in the margarine of about 16 per cent, which means 17–20 per cent aqueous phase, to allow for its content of milk solids, salt and other solids dissolved or suspended therein. With this phase ratio, and particularly when the aqueous phase is slightly acid, the emulsion type is predominantly or entirely W/O. This is always the case in the continuous emulsification process, where the two liquid phases are supplied continuously in constant proportions of 82–84 per cent fatty matter to 16–18 per cent aqueous phase into a high-speed mixing machine or emulsifier. With the emulsion churn, which works at slower speed and on the batch principle, the operator can produce, by special techniques and suitable selection of stabilizer, either complete W/O emulsions or the mixed type according to his preference. Although the finished solid margarine must largely be of the W/O type many manufacturers consider that the presence of a proportion of O/W type of emulsion during the emulsification and working stages of the process, and in some cases also in the final product, is an advantage from the point of view of consistency and flavour quality.

The margarine emulsion, as mentioned earlier, is unstable, and if kept at temperatures above the melting point of the fat-blend it gradually separates in the two phases, the rapidity depending on the efficiency of the emulsion stabilizer. Even the solid margarine, if the emulsion is not stabilized in some way, may show a tendency to phase separation by exudation of drops of water, so-called "weeping" or "leaking" margarine. The finer the dispersion of the aqueous phase the slower the separation which in the solid margarine can be entirely prevented. As it is important for the appearance and keeping quality that there should be no separation in the solid margarine, the manufacturer takes great care to obtain a suitably fine emulsion. It is often stated that the finer the emulsion is, i.e., the dispersion in the outer fatty phase, the better for the margarine. This is only true within limits. As mentioned on pages 103, and 136, taste and aroma in margarine reside essentially in the aqueous phase, and for this to react satisfactorily with the sense organs on the palate there must be rapid access to and exposure of the water droplets when the margarine is consumed. When the water droplets are of very uniform size and extremely small, they may be so fully and tenaciously coated by the continuous fatty phase that their access to the taste papillae is impeded, even when the fat melts in the mouth. In such cases the product gives the rather insipid taste of pure fat instead of one characteristic of the flavour substances from the milk and ingredients. Such extremely fine dispersion of the phase is principally the effect of mechanical mixing and emulsion stabilizers, and the manufacturer aims at an emulsification technique and usage of stabilizers that will give a suitable dispersion and size-frequency variation of the aqueous phase as to obtain the best flavour effect without incurring the risk of moisture exudation from the margarine during working, packing and storage. The solidification, compression and shearing during processing, and changes in the ratio of solid and liquid glycerides with temperature variations, after the emulsion has first been established in the liquid form, subjects the solid emulsion to considerable strain; hence a good and suitably stabilized emulsion is a very important feature of successful final margarine.

The degree of dispersion and stabilization that is considered optimal depends also on some features connected with the fatty phase, namely the melting points of the glyceride fractions and their crystal structure. A rapid melting of part of the fat at temperatures well below that of the body, for example at 25–30°C, will give immediate access to the water droplets, provided the dispersion is not excessively fine. Such a condition in the fatty phase is established, if the crystallization and solidification of the fatty emulsion is caused to take place through initial formation of crystal nuclei of higher-melting glycerides, around which larger, but still microscopical crystals can develop to form a skeletal structure supporting a matrix of lower-melting glycerides. A uniform structure of small micro-crystals lessens the plasticity of the solid margarine and gives a "heavy" sensation on the palate, as does also the coarser crystal-in-matrix structure if the higher-melting precrystallized glycerides have melting-points well above body heat, which may be the case with an unsuitable balance of fats and oils in the fat blend (see page 54). However, even with a suitable structure of the fat a "dry" or "heavy" sensation on the palate can be caused by a too fine dispersion of the aqueous particles.

A numerical indication of a suitable globule size and size frequency distribution of the dispersed aqueous phase is difficult to give, partly because of the mentioned influence of the structure and glyceride composition of the continuous fatty phase, but tests and observations have shown that if 80–85 per cent of the globules have diameters of 1μ or less and the remainder not above 3μ a very dense "fatty" product is obtained. Margarine with about 95 per cent globules of diameter 1–5μ, 4 per cent of 5–10μ and 1 per cent 10–20μ is usually "light" on the palate. The presence of about 1 per cent of larger globules, up to 30–40μ in diameter, is an advantage as to flavour, but entails a risk of exudation and reduced keeping quality. The number of water globules in a very fine dispersion may be of the order of 10,000–20,000 millions per gram or even higher, but even a very small proportion of these as relatively large globules accounts for a fairly high proportion of the total moisture.

A very fine dispersion of the aqueous phase helps to protect the margarine against deterioration by micro-organisms; very few of these thrive on fat, and only if moisture is present. Infection from the air finds it difficult to establish itself if the moisture droplets are encased in fat, and even infections in the droplets may in many cases die out as the surrounding fat may prevent access of air for those organisms which require oxygen, or the amount of nutrient in the minute droplets may be insufficient to support growth and development. These droplets are smaller than many of the undesirable micro-organisms such as yeasts and moulds, and these rarely develop in droplets of 40μ or less. The bacteria are smaller and frequently of the same order of magnitude as the smallest droplets, but as in bacteriologically well controlled margarine the number of droplets far exceeds the number of bacteria, many of them will be sterile and the infected ones so low in nutrient, that the organisms are soon weakened and even die.

Emulsification is therefore a very important step in the making of margarine, and in the days when the scientific knowledge of the principles involved in the processes was less developed, the skill and art of the "churn-master" played an important part in the successful manufacture. Experience and certain empirical tests guided him in establishing the desired emulsion, and in the then universally, and still very frequently, used Emulsion Churn he had a plant which lent itself to a diversity of methods to obtain the kind of emulsion he aimed at. The introduction in many factories of continuous emulsification plant lessened the demand for individual skill and relied more on mechanical control, but against simplicity and reduced process cost of this continuous plant some flexibility was sacrificed, and the type of emulsion was more rigid.

While churns and continuous emulsifiers effect emulsification as a first and separate process prior to solidification of the emulsion by cooling, followed by separate kneading or plasticizing very recent processes and plants have been introduced, in which the three steps, emulsification, cooling and kneading, are combined. These will be described in a later chapter, page 228, in connection with plants for continuous processes.

2. EMULSIFICATION PLANT AND TECHNIQUE

Emulsion Churns have been used since the earliest days of margarine manufacture, and although improved from time to time, for example by using better and more suitable metals for construction and electrical driving gear in place of belt and pulley, the type and design used nowadays in factories working on the batch principle has changed very little during the last 40–50 years.

Fig. 30 shows a typical churn of the belt-driven type. It is a jacketed cylinder of oval cross-section, the inner cylinder being of heavily tinned steel or, in more recent constructions, of stainless steel. The jacket *F* permits heating or cooling of the churn contents by means of water for which inlet *J* and overflow *K* are provided. Valve *H* admits steam to a perforated pipe for heating the water. The churn is provided with two agitators driven at *D* and *E* by separate bevel gearing off the same shaft with fast and loose pulleys at each end. The agitators are of strong construction and consist of a heavy vertical shaft resting in bottom bearings and have upper and lower horizontal

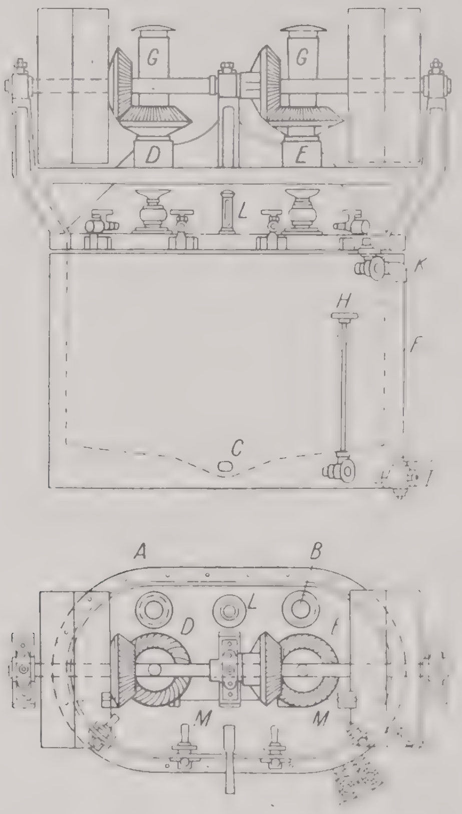


Fig. 30. Diagram of emulsion churn.

radial arms connected with 6–8 flat bars, which are either vertical or, if the top and bottom arms are slightly recessed, may form very steep screw planes; they are often twisted to form an angle with the radial arms. The agitators are intercalating and revolve in opposite directions. The flat bars have a number of holes of about 1 in. diameter which greatly assist emulsification through the shearing effect, see Fig. 31. It is important that the agitator sweeps close to the vertical shaft of the other and to the wall of the churn to prevent the formation of solidified or overheated layers when cooling or heating. The bottom of the inner vessel slopes towards the outlet *C* to ease draining of the viscous emulsion. Part of the cover is hinged *M* and can be opened up for inspection and addition of ingredients. Inlet pipes for the tempered fat-blend and for milk or other aqueous phases connect with the cover at *A* and *B*, and these pipes sometimes join up with ventilators *G* for venting the churn during filling and emulsification. A thermometer at *L* enables the operator to check the temperature of the emulsion during the process, and a circular sight glass, which is often found in the hingeable cover, shows by drops deposited on it how emulsification progresses.

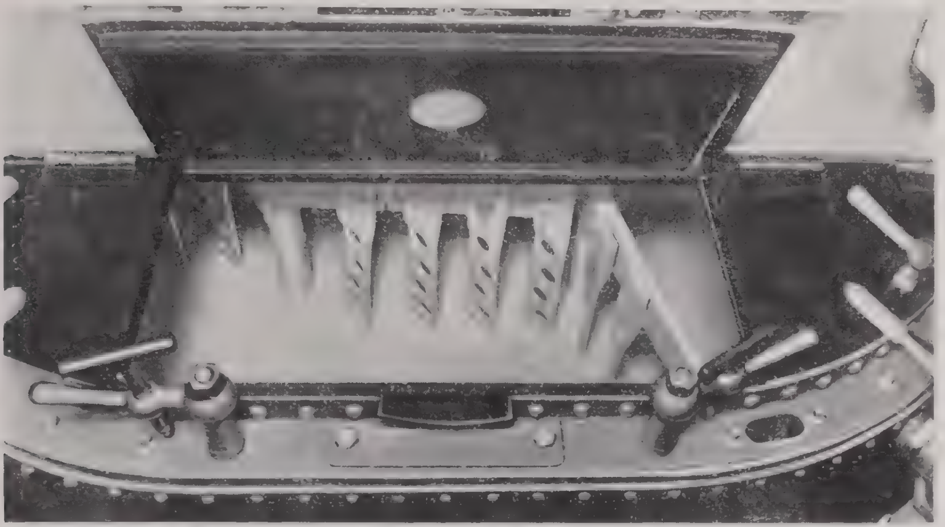


Fig. 31. View into emulsion churn (Courtesy: *Van den Berghs and Jurgens Ltd.*).

Fig. 31 shows a view into a churn through the opened cover and illustrates several of the features mentioned.

Fig. 32 shows a front view of a churn of this type.

The churn shown in the section diagram in Fig. 33 is constructed for drive by a 15 h.p. variable speed electric motor, but is otherwise similar to those described in its principal features. There are 3 inlets, namely for the oil or liquid fat-blend, the milk and the salt solution.

The volumetric capacity of churns vary from about 0·25 cubic metre to about 4 cubic metres, the working capacity is 60–70 per cent of the volume.

The power required to drive the agitators varies with the capacity of the churn and the thickness or viscosity of the emulsion; for a churn of 1·5–2 tons working charge 10–15 h.p. should be provided. With a churn of this type, where a variable agitator speed of up to 180–200 r.p.m. is required, obtained either by a variable speed motor or by belt-drag on the pulleys. the operator can adjust the character of the emulsion by varying his technique according to raw materials and ingredients and their proportions, and according to his ideas as to the best emulsion for his final product. There is no hard and fast rule, as the technique and results obtained in the emulsion churn have to be considered in relation to subsequent steps in the process. Some examples of the different methods which are principally used are given

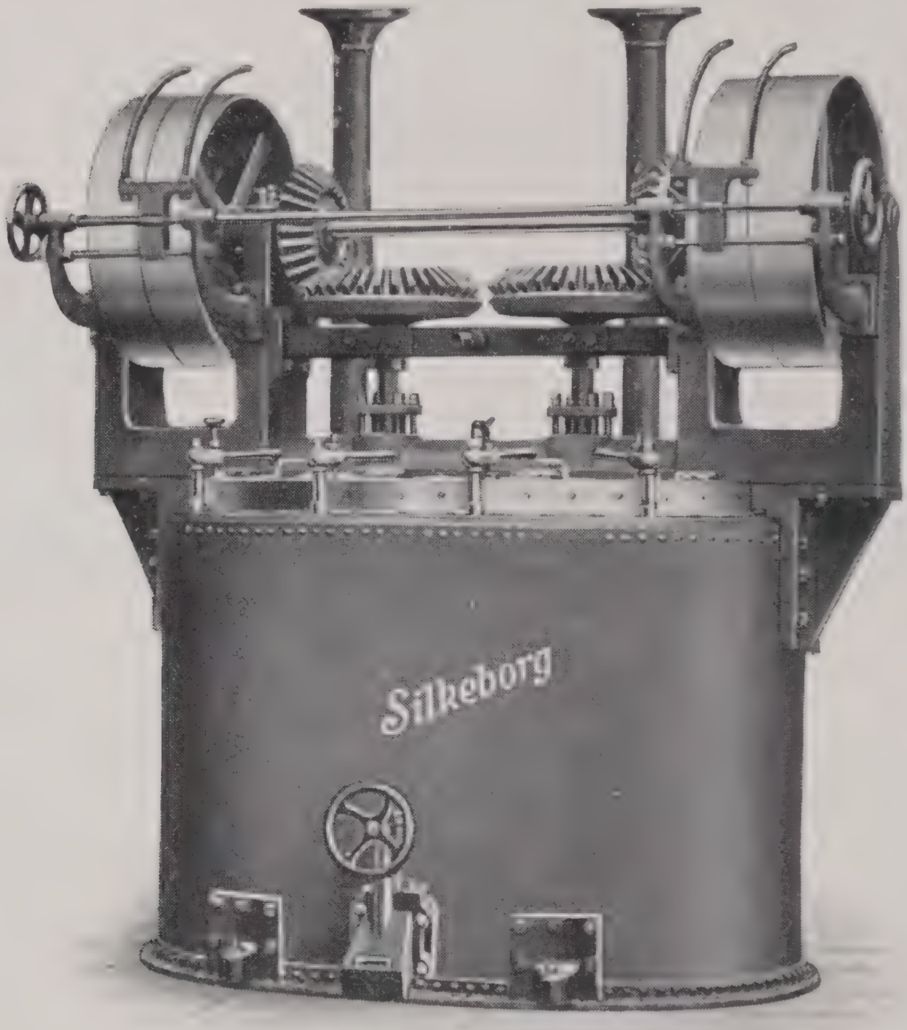


Fig. 32. Emulsion churn (Courtesy: *Silkeborg Engineering Works*).

below; for complete control it is not only necessary to be able to regulate the agitator speed, as already referred to, but to have rapid control of temperature changes by means of hot or cold water in the jacket. A perforated steam coil is required to heat the water in the jacket, but steam in the jacket is deprecated. It should be possible to drain the jacket quickly for replacing warm with cold water and vice versa, and many manufacturers have available crushed ice from sterile water, ice water or a cold salt-brine solution to add direct to the contents of the churn for rapid lowering of the temperature; ice is particularly useful because of its latent heat of fusion.

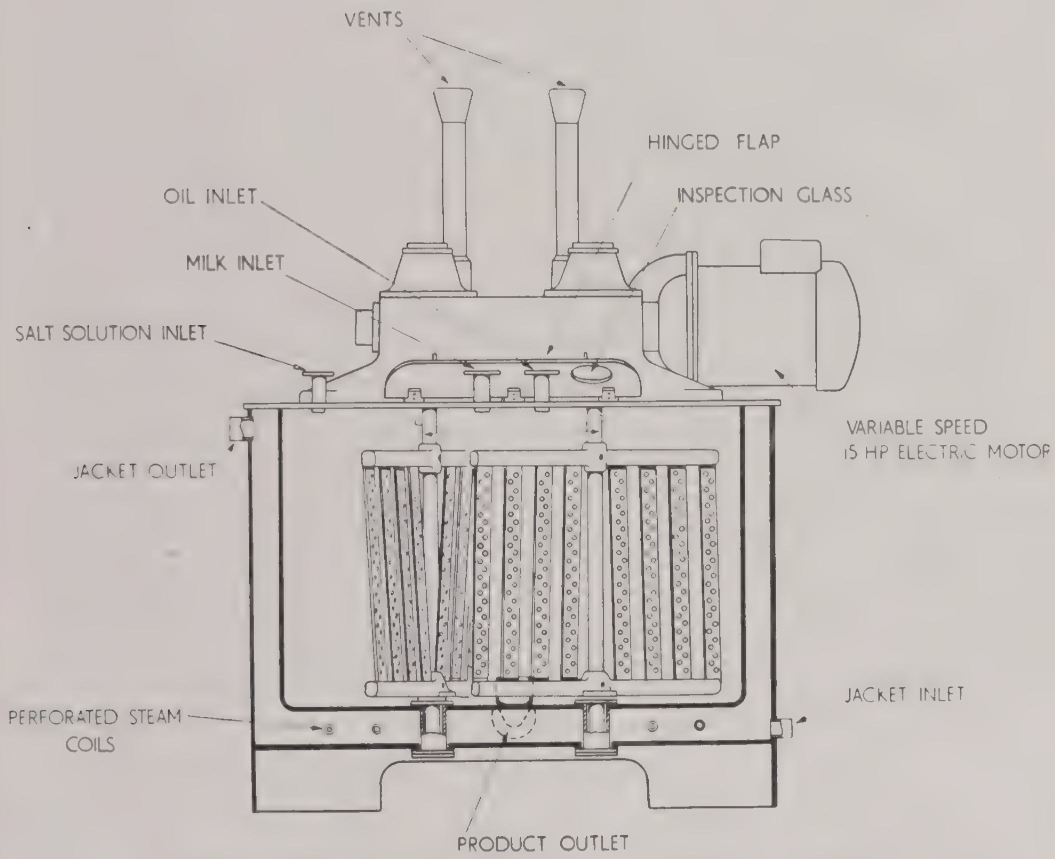

VENTS
HINGED FLAP
OIL INLET
INSPECTION GLASS
MILK INLET
SALT SOLUTION INLET
VARIABLE SPEED
15 HP ELECTRIC MOTOR
JACKET OUTLET
JACKET INLET
PERFORATED STEAM
COILS
PRODUCT OUTLET

Fig. 33. Diagram of emulsion churn (Courtesy: *W. J. Fraser & Co. Ltd., Dagenham*).

As regards speed of agitation the important point is the peripheral speed of the agitators; therefore a higher speed of rotation should be obtainable on smaller churns than on larger. The position and construction of the agitators are of importance; single agitators do not give good control of emulsions, hence the universally accepted double agitator design with the paddles moving in opposite directions. They should, as stated, sweep close to the wall and bottom of the churn to avoid stagnant semi-solid skin formation. As particularly with thick emulsions a high proportion of air is beaten in, the working volume is often considerably less than the total volume, and some churns give best results with 50 per cent filling, others, and more generally, with 65–75 per cent filling. The fineness of the emulsion and dispersion depends as much on the effect of the stabilizer as on the speed of agitation and the latter should be adjusted so that excessive aeration is avoided, as this may lead to instability of the emulsion; an increase of volume by 20–25 per cent by aeration should not be exceeded. The ventilator pipes or vents in the churn lid should be free from obstructions, so that excessive air discharged from the aerated emulsion or released by increase in temperature can escape freely. If aromatizing or vitaminizing ingredients are added in the churn they should be added near the end of the churning period, preferably after the speed of agitation has been reduced to medium or less a few minutes before the churn is emptied. An observation glass in the lid of the churn will show, from drops of emulsion deposited on it, whether the operation proceeds as desired; many operators prefer, however, to reduce the speed to minimum from time to time and open the churn lid for visual inspection and sampling.

Tempering tanks for the fat-blend (see page 63) are usually placed conveniently under control of the churn operator to enable him to run supplies into the churn as he requires, according to his method of churning; similarly, he should have at the churn a measuring vessel of suitable size for the milk or other aqueous phases from which he can draw in such proportions as he wishes.

The following examples indicate the principal methods used in churning practice. The proportions of the materials are in modern works nowadays usually 80–83 per cent fat-blend and 17–20 per cent aqueous materials. The temperature of the former from the tempering tank is as a rule close to, for example 2–3°C above, the melting point, which for most blends is 32–35°C. The milk or aqueous phase is not more than 7–10°C, but some operators prefer to have it cooled to 3–4°C.

Where a straightforward water-in-oil emulsion is aimed at, the two phases can be run into the churn at the same time through the separate inlets, while the agitators run at high speed, 150–200 r.p.m.; the jacket temperature is similar to that of the fat. The proportion of the phases and specially the presence of fat-soluble or balanced emulsion stabilizers cause the immediate formation of a W/O type of emulsion, the fineness of the dispersion depending on the degree of agitation and particularly on the efficiency of the stabilizer. After some 10–15 minutes stirring, when the droplets on the inspection glass shows the emulsion to be uniform, the temperature in the jacket is lowered by admission of cold water; the emulsion gets more viscous, the droplets on the glass become opaque and lighter in colour by the finer dispersion and occlusion of air in the thickening emulsion, and the temperature which has been falling steadily becomes stationary or may even increase a few degrees. This is a sign that crystal formation begins in the fat and latent heat is released. With a temperature in the jacket similar to the setting point of the fat, usually 7–8°C lower than the melting point, or 24–27°C, the temperature begins to fall again after a time, indicating that the formation of microscopical crystal nuclei, which is very important for the subsequent solidification and plasticizing of the product, has taken place and that the emulsion is ready for discharge to the cooling plant for solidification. The speed of the agitators is now reduced to medium, the temperature in the jacket increased to about 40 C and the emulsion warmed up a few degrees, for example to 30–32°C, which does not affect the already formed crystal nuclei, but prevents formation of macroscopical crystals which would cause grittiness in the solidified margarine. Increasing the temperature of the emulsion at the end of the churning process is particularly useful in connection with the dry cooling process on drums, see next chapter, as it permits the easier application of a thin layer of emulsion to the cooling surface. When the desired temperature is reached, the agitators are set to slower speed, 60–70 r.p.m., and the emulsion passed on to the next process step. As fat blends and their melting points vary with climates and seasons the temperatures indicated in this example have to be modified as conditions demand, and are given here by way of example. The method is used frequently when coconut oil or palmkernel oil form the major portion of the solid fats in the blend, and some operators reduce the churning temperature to as low as 20–22°C because of the low setting point of these fats. To hasten the cooling to such lower temperatures addition of crushed ice to the emulsion is often resorted to, the amount varying, but is generally 5–6 per cent of the weight of the fat; the aqueous phase is then reduced by the corresponding amount.

A slightly different procedure is used in some works, also preferably for coconut-palmkernel oil margarines. The fat-blend at 36–38 C is run into the churn with a jacket temperature of about 32°C and under medium stirring. When all the blend is in, crushed ice is added to it and cold water to the jacket. The stirring speed is gradually increased to 150–180 r.p.m. and the aqueous phase at 8–10°C added. The churning temperature is thus reduced to 23–25 C and emulsification should be achieved in 10–15 minutes. The speed is then reduced to 60–70 r.p.m., lukewarm water is admitted to the jacket, the temperature of the emulsion increased to about 28°C and the product passed on to the cooling device. Fat-soluble ingredients, if added in the churn, should be added to the blend before the ice, water-soluble ingredients while the milk runs in. Fat-soluble vitamin preparations and water-soluble aroma ingredients should, however, be added a few minutes before the finish of emulsification.

There are factories where no attempt is made to induce formation of crystal nuclei in the churn. For example, the fat-blend with a temperature 3–5 C above its melting point is first run into the churn and is followed by the aqueous phase while the agitators run at full speed. Churning then takes place for about 10 minutes at 3–5°C below the blend inlet temperature while the jacket is kept lukewarm; full stirring speed is maintained while the contents of the churn are pumped to the cooling plant for immediate solidification. Owing to the absence of initial crystallization in the churn, regulation of the correct structure of the final product is achieved by suitable tempering or maturing of the solidified emulsion before kneading and plasticizing.

Margarine blends in which the solid fats mainly contain glycerides of palmitic, stearic and "iso-oleic" acids, i.e., oleo, premier jus, lard, palm oil and partly hydrogenated fats, are usually churned by slightly different techniques. One method is to run into the cold churn all the cold milk or aqueous phase at full stirrer speed; this breaks the milk curd up into very minute particles. While the churn jacket is kept cold, the blend is next run in, and churning proceeds at full stirrer speed and at a temperature 5–10°C below the melting point of the blend. When a good thick emulsion is established and the temperature is steady after the small increase due to nucleic crystallization, the emulsion is, by increasing the jacket temperature, warmed up to about 3–5°C above the blend melting point, while reducing the stirrer speed to 80–100 r.p.m., and finally pumped to the cooling plant at slow agitator speed.

Margarines made specially for use in flaky or puff pastry should be of tough firm consistency and are usually made from a blend containing a fairly high proportion of high-melting fat (see page 57) and liquid oil and therefore has a high melting point, about 40–45°C. This quality should be emulsified at higher temperature than table margarine and is often churned by running the fatty phase at about 65°C and the aqueous phase at about 10°C into the churn with a jacket temperature of 65–70°C while the stirrers run at high speed. The two phases should be run in pro rata so that the full amount of each is in at the same time. In this type of margarine the moisture percentage is rarely more than 10. If ingredients are to be added in the churn they should be put in when $\frac{1}{4}$–$\frac{1}{3}$ of the contents of fat are in. During churning, after all the components are added, the temperature is adjusted to 50–55°C and after about 15 minutes final churning the emulsion is ready for discharge.

Another method for the table margarine type of fat-blend is the so-called "two emulsion" process. In this a minor proportion of the blend is first emulsified with about half the aqueous phase, and when a thick primary emulsion is established the remaining blend and aqueous phase is added and emulsification continued. The primary emulsion acts as an emulsifier for the remainder. For example, 30 per cent of the fat-blend at 40°C is added under rapid stirring to half the cold aqueous phase, which has first been run into the churn. Churning with the jacket cold lasts about 8 minutes and a good thick emulsion should then have been formed. The remaining 70 per cent of the fat-blend and the remaining half of the aqueous phase are then run in at the same time, churning at full speed being continued for about 10 minutes after filling. The emulsion temperature is adjusted to about 30°C, and the contents are then ready to be discharged. In these methods with the aqueous phase in excess from the beginning ice is rarely required unless fairly high-melting blends are needed for climatic reasons. In such a case the following method may be used: With the churn jacket cold about 5 per cent of the blend at 40–42°C is run in, and immediately afterwards the ice, corresponding to 3–4 per cent of the blend, is added. Stirring then starts at fast speed and about $\frac{1}{3}$ of the blend and $\frac{2}{3}$ of the aqueous phase are added at the same time and churned about 5–10 minutes, when a good thick primary emulsion should have been formed. The remainders of the blend and the aqueous phase are then added pro rata in course of 10 minutes under full speed stirring. Agitation is then slowed down, ingredients, if any, added and a further 5 minutes' stirring makes the emulsion ready for discharge. The temperature of the emulsion should be about 35°C when finished if the blend has a melting point of about 40°C. With a blend of lower melting point the same procedure can be used, but the temperatures right through the churning process should be correspondingly lower.

Churning methods in which a primary emulsion is formed with a high proportion of milk or aqueous phase often lead to a final margarine emulsion in which the two types of emulsion are present, namely a smaller proportion of the O/W type from the primary emulsion dispersed together with water droplets in the larger proportion of emulsion of the W/O type. This is particularly the case, if the milk used is of the unripened quality with a pH of 6·3–6·7 or if the ripened milk has been substantially neutralized with alkali to bring the pH above 6·2 (see page 94). It can also happen if strongly hydrophilic or efficient balanced emulsion stabilizers are used. Some operators deliberately induce this kind of emulsion formation by using as aqueous phase a mixture of ripened and unripened milk and adding to the primary emulsion 0·3–0·5 per cent egg yolk and 0·2–0·3 per cent lecithin diluted with oil, or about 0·3 per cent of a chemical emulsion stabilizer of the monoglyceride-sodium sulphoacetate type. It is often held that the presence of a minor proportion, 15–20 per cent, of an O/W emulsion in the W/O margarine, similar to the kind of double emulsion found in butter, leads to special advantages in consistency and plasticity in the final product. This opinion is similar to that forming the basis of B.P. 614,925 (see page 136) although that patent specifies a difference in the composition and melting point of the blends for the primary and the final outer fatty phase.

A complete O/W emulsion of the type of a highly concentrated cream with about 80 per cent fat, similar to that used for the continuous production process for butter (see page 128) and as referred to in a British patent from 1912 [152], can be made in the churn by using as aqueous phase fresh unripened skim milk, preferably with an addition of 0·25 per cent egg yolk and 0·25 per cent lecithin, calculated on the final amount of emulsion. The milk and emulsion stabilizers are warmed in the churn to about 5°C above the melting point of the fat-blend, and the latter is then slowly and continuously added to the milk while stirring at high speed, about 250 r.p.m. The emulsion, while being formed, is slowly warmed by the jacket to 10–15°C above the melting point, but such a highly concentrated emulsion of 80–82 per cent fat is rather unstable, and addition of salt or mechanical working after completion of churning tends to break it and invert it to the W/O type or a mixture of the two types, hence it cannot be discharged from the churn by pumping, but should be run out by gravity; it is a thick viscous product and soon solidifies at room temperature. Certain fat-blends, which by rather slow cooling lead to formation of coarse crystals of fat, for example blends with high proportions of coconut and palmkernel oils, tend to break the emulsion during setting and cause exudation of moisture, but blends with small-crystalline animal fats or semi-hydrogenated oils will set as a margarine of quite good texture and plasticity and can be run direct into the final containers. The keeping quality, in the absence of salt and with unripened milk is, however, rather poor. As an O/W emulsion this concentrated cream cannot be rapidly solidified by the ice-water cooling method, see later, as the water acts as a diluent, and before solidification takes place considerable losses occur through the running off of the ice-water. Cooling by the dry method on double-cylinder drums leads to partial inversion of the emulsion, and on single cylinders difficulties are found in applying and spreading the thick emulsion in a uniform layer on the cooling surface. Practical difficulties have therefore militated against the use of this system of emulsification and nearly all margarine is therefore made by methods aiming directly at a W/O emulsion or a double emulsion by the "two emulsion" system as described.

A few more examples of slightly different details of methods should be described as they are favoured in several factories.

The "seeding method" consists in using a small proportion of finished solid margarine to initiate the formation of emulsion and crystal nuclei in the churn. With the churn jacket cold, 3–4 per cent of margarine, calculated on the final churn charge, are placed in the churn as "seeding" material together with about $\frac{1}{3}$ of the aqueous phase; the agitators are started at medium speed and $\frac{1}{5}$ of the fat-blend run in at about 40°C, while the stirring speed is gradually increased to full speed in 8–10 minutes. When a thick emulsion has been formed in this way, ingredients are added and the remainder of the aqueous phase and fat-blend and all churned together at full speed for about 20 minutes. The temperature of the emulsion when finished should be 26–28°C if the wet cooling method is used, 30–32°C with dry cooling. Some manufacturers make a special "seeding" margarine from a blend of fats which tend to solidify in small crystals, such as semi-hydrogenated groundnut oil or cottonseed oil, and use this to promote the formation of crystal nuclei.

In the methods described so far the fatty phase is used in the form of a mixture of all the constituent fats and oils of the blend. Some operators favour for certain qualities the "split-blend" method in which some of the fatty components are used separately. For example, a margarine made from coconut oil, semi-hydrogenated fat and liquid oil as fatty raw materials may be churned as follows: The coconut oil, which forms 30 per cent of the blend, is at 28°C run into the churn with a jacket temperature of 26°C which prevents the fat setting on the wall; all the milk is then run in while stirring at 140–150 r.p.m. and churning continued about 5 minutes; 4 per cent crushed ice is then added, and after a further 10 minutes churning at 150–200 r.p.m. a good thick emulsion results, the temperature being 26–27°C; the remainder of the blend, the hydrogenated fat and the oil, at a temperature of 38°C, is then added to the primary emulsion in course of 5 minutes and the contents churned together for 10–12 minutes while the emulsion temperature is adjusted to about 35°C, when the product is ready to be discharged for cooling.

Other operators prefer to form the primary emulsion from the liquid oil portion of the fat-blend and about $\frac{2}{3}$ of the aqueous phase plus crushed ice. After churning a few minutes and bringing the emulsion temperature up to 28°C, the blend of the solid fat, melted and adjusted to about 40°C, and the remainder of the aqueous phase are run into the churn slowly and churning continued for 10 minutes after all has been added; the emulsion temperature is lowered to about 30°C, when the contents are ready for the cooling plant.

Fig. 34 shows a view of an installation of churns in a large factory. The cylindrical vessels above the churns are used for measuring the milk or other aqueous ingredients; in the background are seen trucks with smaller cylindrical cans for measuring crushed ice and diverse additions made to the emulsion in the churn.

There are many variations in details of the methods of churning, and those described only indicate the guiding principles; each operator has usually his own favoured procedure. The churning process was in earlier days surrounded by much mystery and ritual, as comparatively little was known of the chemistry and physics of the fats and of the physical chemistry of emulsions. Each operator, churnmaster, had to acquire, partly by tradition partly by trial and error, his experience how to deal with the emulsification problem with varying physico-chemical and colloidal characteristics of the milk or aqueous phases and with the changing oil and fat compositions. With the wet cooling method being the only one then used, a good close emulsion was essential to minimize losses of fat and milk, and the modern emulsion stabilizers were not available then, except egg yolk which was first introduced as a "browning" ingredient. With the dry cooling method displacing gradually the ice-water method since 1910, and with increasing scientific knowledge of the principles involved, as well as with the the development of efficient stabilizers, the emulsification problem became easier to solve. The skilled operator could adjust ingredients and technique to suit the new fats coming into use and realized that emulsification was only one link in the chain of processes to obtain the desired final product, and that each of these played an important part in determining the consistency and texture of the margarine, as well as its palate sensation. This inter-dependency of the various steps in the process is particularly important, when the short continuous emulsification process was introduced, as a logical step from the introduction of continuous dry cooling; in the latter the instantaneous solidification of the liquid emulsion prevented largely separation, and as the emulsion was only in contact with dry surfaces, washing-out losses were avoided.

Continuous Emulsifiers.—In such machines the materials pass through continuously in pre-determined proportions of the two phases in a very short time, usually a few seconds; the temperature of emulsification is therefore largely determined by the temperature and ratio of the phases, although the machines are often jacketed to help temperature control. With small machines and large throughput there is, of course, little opportunity of drastic change, apart from emulsification, during the passage; there is consequently little scope for manipulation or regulation of the emulsion for initiation of nucleic crystallization, and because of the constant phase ratio the emulsion type is, with the usual kind of stabilizers, definitely W/O. In some of the earlier continuous emulsifiers the rather coarse dispersion resulting from the short mixing period, even if stirring was at much higher speed then in the churns, was considerably improved by passing the emulsion through a homogenizer, where by being forced under high pressure through capillary channels or slits the water particles in the fat were broken up and comminuted into

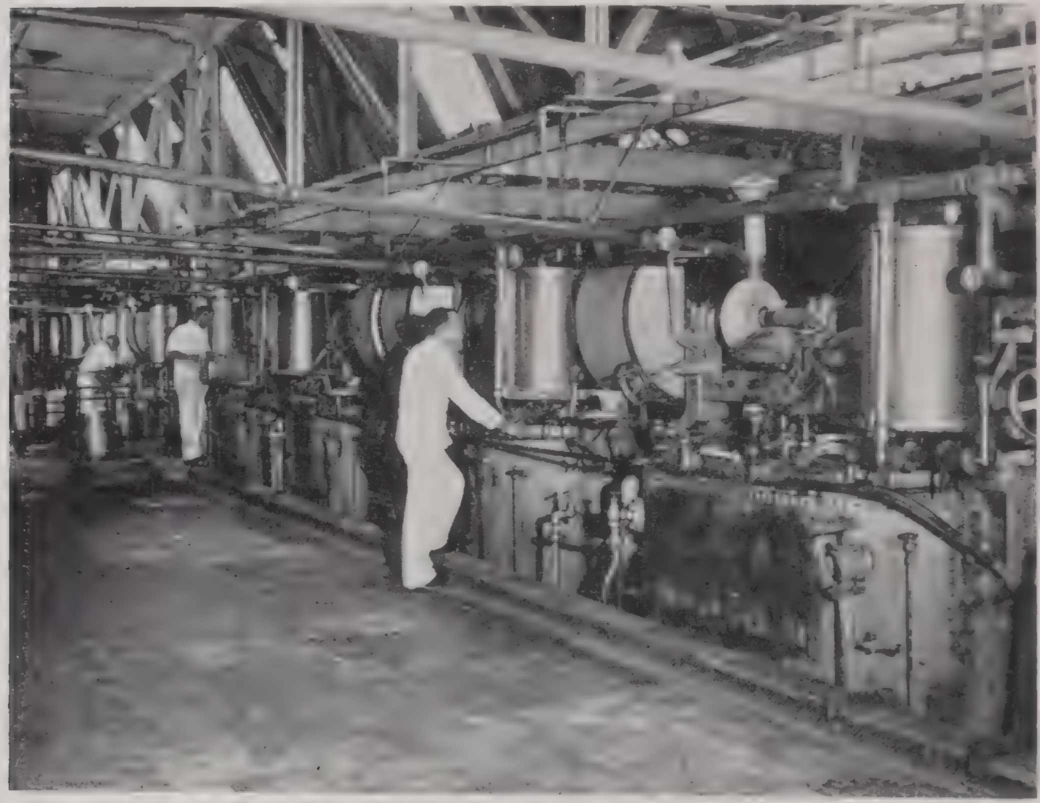


Fig. 34. View of churn installation (Courtesy: *Van den Berghs and Jurgens Ltd.*).

extremely fine globules. This treatment helped towards stabilization of the emulsion, which was particularly important where wet cooling was used.

One of the earliest plants for continuous emulsification was the combined churn and homogenizer made by *Schroeder & Co.*, Lübeck [153] about 50 years ago. Blend and milk in the required proportions were admitted to a small churn until it was about 60 per cent full; the contents were then mixed under high speed of the two paddles, 500–600 r.p.m.; after a couple of minutes the premixed emulsion was drawn from an outlet at the bottom of the churn and passed under high pressure through a homogenizer, while blend and milk was admitted to the churn at the rate of withdrawal of emulsion, thus maintaining the level in the churn. A three- or four-stroke piston pump was used for forcing the emulsion through the homogenizer valve, the pressure on which could be regulated by a special valve and a spring-loaded safety valve. This arrangement gave a continuous flow of a good W/O emulsion. Sometimes two or three superimposed small churns were used for pre-mixing. The plant which was already used with the wet cooling system is now considered out-of-date.

The introduction of the dry cooling system led to the development of several types of high-speed emulsifiers. A very simple type, consisting of a short cylindrical tube of about 8 in. diameter with a central shaft with a number of propeller blades revolving at 3000 r.p.m., and into which the two phases are supplied by proportioning pumps in the correct ratio, gives a W/O emulsion of sufficient stability, when used in fair proximity to a solidification and cooling plant of the double-cylinder type, but very efficient emulsion stabilizers are required when the cooling plant is of the single-cylinder type, as the emulsion otherwise tends to separate in the feeding through for the cylinder. As most cooling plants of the drum type nowadays are with single cylinders, more efficient types of continuous emulsifiers have been introduced and found wide application in connection with the modern continuous processes of cooling and kneading.

As an example of such an emulsifier Fig. 35 shows a diagram of a section

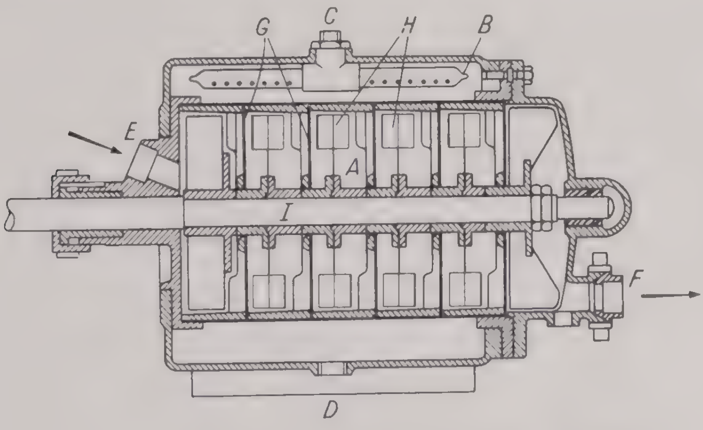


Fig. 35. Continuous emulsifier (Courtesy: *Silkeborg Engineering Works*).

through the Silkeborg emulsifier; to obtain with this a stable emulsion it is recommended that an emulsion stabilizer should be used, and this recommendation applies to all continuous emulsifiers for the W/O type of emulsion. The Silkeborg emulsifier has an emulsion chamber *A* surrounded by a jacket *B* for temperature regulation by water with inlet *C* and outlet *D*. The fat-blend, milk and dissolved ingredients enter premixed the chamber at *E* and leave as a fine emulsion at *F*. The chamber is provided with a number of stationary removable perforated baffle plates *G* between which beaters *H*, fixed to the shaft *I*, rotate at high speed, usually by direct motor drive, Fig. 36. Surfaces coming in contact with the emulsion should, particularly if salt is dissolved in the aqueous phase, be made of a suitable alloy of stainless steel. The temperature should be regulated by the jacket so that a fairly thick viscous emulsion leaves the machine for the cooling plant. The two phases with the appropriate ingredients dissolved can be supplied in desired constant proportions to the machine direct by suitably dimensioned pumps via the inlet pipe, but the preferred method is to use the emulsifier in conjunction with two pre-mixing tanks. These are jacketed vessels with stirrers; horizontal semi-cylindrical tanks or vertical cylinders of the churn type are used, but of much lighter construction. In these the materials are pre-mixed and tempered in the right proportions, and by suitable manipulation and adjustment of temperatures it is possible to initiate the nucleic micro-crystallization of some of the glycerides, which would not be possible by the short passage of the emulsion through the emulsifier. Two pre-mixers are used alternately to ensure a continuous supply to the emulsifier, and they

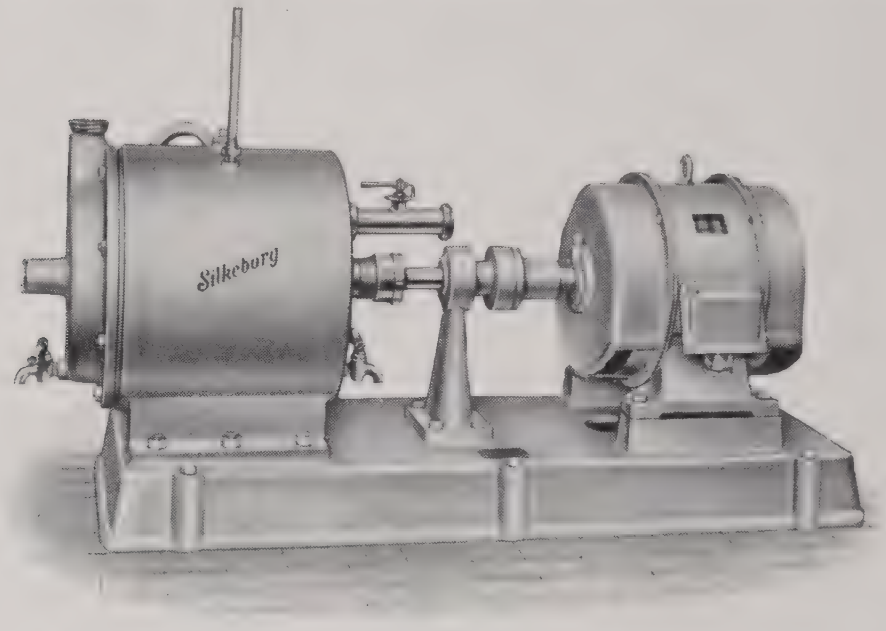


Fig. 36. Silkeborg motor-driven emulsifier for continuous working (Courtesy: *Silkeborg Engineering Works*).

should have a capacity equal to about half-an-hour's supply for the emulsifier.

An installation of this kind is shown in Fig. 37. The two pre-mixers supply alternately the mixture to a continuous emulsifier of the centrifugal pump type connected with an "atomizing" device which with small power consumption, 3–4 kW, gives an emulsion ready for supplying to the cooling cylinder.

There is a variety of continuous emulsifiers operating on similar principles and some of them are constructed for the dual purpose of emulsifying and pumping the emulsion to the cooling plant. The "Emulsator" pump used on the Gerstenberg continuous plant (see later) is also of the centrifugal pump type equipped with impellers and comminuting devices and can lift the emulsion a considerable height in case the cooling cylinder is placed at a higher level. Fig. 38 shows the direct motor driven "Emulsion Rotor" made for the same purpose by *Schröder & Co.*, Lübeck.

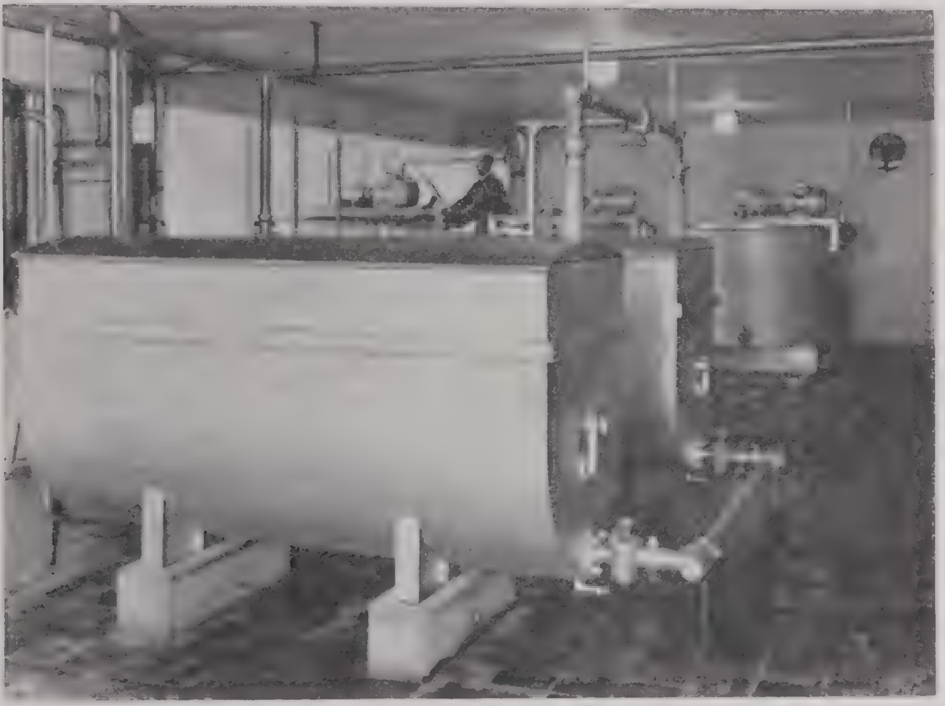


Fig. 37. Pre-mixing plant for continuous emulsification (Courtesy: *Atlas A./S., Copenhagen*).

A procedure for emulsification that has found favour in many factories consists in running the phases into one of the pre-mixing tanks under stirring, adding the ingredients and adjusting the temperature by means of the jacket to that required for emulsification. The contents are then drawn by the emulsifier pump from the bottom of the pre-mixer and returned to the surface of it and thus circulated for 15–20 minutes until the emulsion is considered sufficiently fine. During this period temperature adjustment can be made for pre-crystallization of nuclei, if desired, and finally the finished emulsion is discharged into the other pre-mixer which they functions as a supply tank for the cooling and solidification plant. This system is often referred to as the Circulation Emulsification method. By suitable dimensioning continuity of operation is ensured.

The continuous emulsifiers described above all give the W/O type of emulsion; if a strong hydrophilic emulsion stabilizer is used, which is, however, rarely the case, a small proportion of the opposite emulsion type may be present. As mentioned on page 149 it happens occasionally that the manufacturer wishes to form the emulsion as a complete O/W or cream type and, as explained, that can be done in the churn provided certain precautions are adopted as to pH value of the aqueous phase and a special technique is adopted. A continuous emulsifier for this type of emulsion was designed by Blichfeldt [154] and operates on the principle of the incoming milk being gradually enriched with fat which is dispersed in it during the passage towards the outlet. Fig. 39 shows a drawing of this machine. The shaft *A*, driven by electric motor or pulleys, rotates the circular disc *B* between covers *C* and *D*, held together by a number of bolts *E*. The distance between the revolving disc and the casing can be adjusted by the bolts and a packing round the periphery; it is usually 0·1–0·2 mm. The speed of the disc is 1000–1500 r.p.m. Unripened skim milk of about 15°C is admitted through the channel *G* to the central chamber, and the fat blend at about 5°C above its melting point is injected via the revolving fat-distributor sleeve *H* through

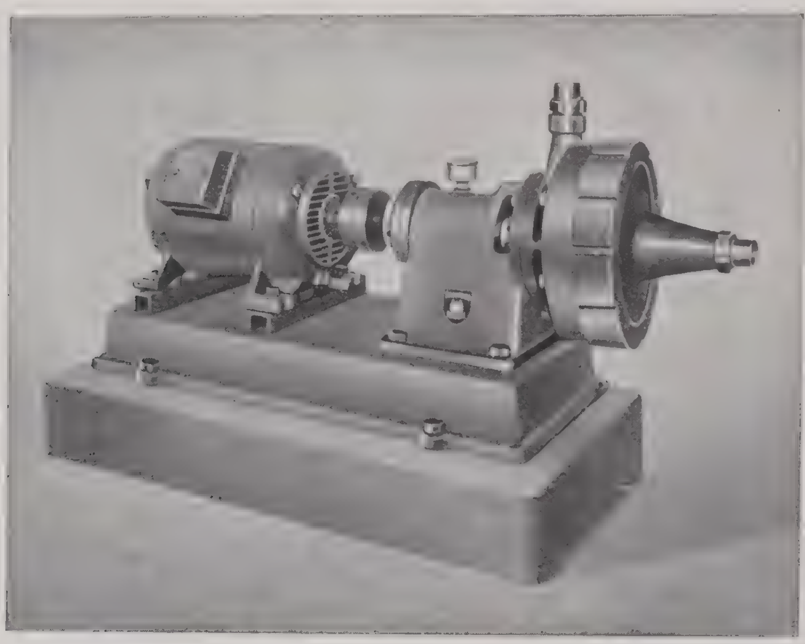


Fig. 38. Emulsion rotor (Courtesy: *Schröder & Co., Lübeck*).

a number of fat-ducts *I*, registering with apertures in the sleeve. These ducts inject the blend at a number of points across the surface of the disc, which has a number of slots *F* that enable the emulsion to move towards the periphery on both sides of the disc. As this is loosely fitted laterally on the shaft, it is self-balanced so that equal quantities pass along both sides. The emulsion travels toward the outlet *J* near the edge under pressure of the proportioning pumps for milk, 16–18 per cent, and fat-blend, 82–84 per cent, and also drawn by the centrifugal force from the revolving disc, while it is being gradually enriched in fat content, until the final cream emulsion with about 83 per cent fat emerges as a very thick viscous liquid with a temperature of 55–60°C, as considerable heating up occurs as the result of friction and homogenizing of the fat-globules. Considerable power is required for driving this machine, 15–20 kW, for a throughput of 0·75–1 ton pr. hour, in comparison with 3–4 kW for an emulsifier of similar capacity producing the W/O type of emulsion; if for some reason, such as too low pH or unbalancing of emulsion stabilizers, inversion of the O/W emulsion into W/O happens during the run the power consumption immediately falls to about 4 kW. The cream emulsion produced in this machine has certain draw-backs, as described on page 150 in connection with the formation by churning of a similar type, but being a cream it can be pasteurized and in certain cases sterilized without separation and thus improved in keeping quality, and with a judicious selection of slow crystallizing fats for the blend it can be filled direct into dispatch containers for slow cooling and solidification, although the consistency and texture are not as good as from shock-cooled margarines. If it is mechanically kneaded for consistency improvement phase inversion takes place and the emulsion stability is likely to be upset.

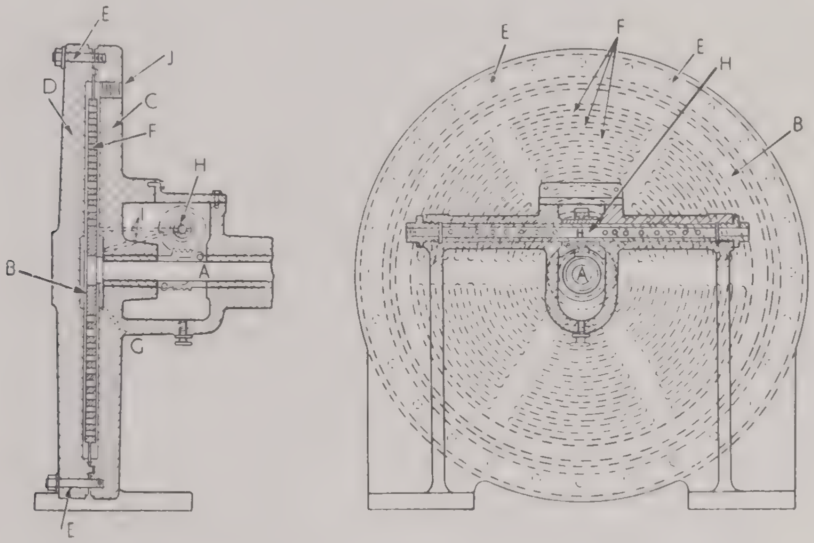


Fig. 39. Blichfeldt cream emulsifier.

This method of continuous emulsification has therefore not been widely used, but it is useful for synthetic margarine creams of lesser fat content.

Margarine cream emulsions have often been used for the manufacture of margarine by the conventional butter churning system, particularly in smaller factories with limited distribution area, as the keeping quality of the product is usually inferior to that of the more conventional type of margarine. The system involves the production in the first instance of a margarine cream of 30–40 per cent fat concentration by dispersing the liquefied blend in skim milk, often with the addition of a small percentage of full-fat milk. This can be done in continuous emulsifiers or by gradual enrichment in churns, with or without stabilizers; unripened milk is a good stabilizer, egg yolk and lecithin likewise. The margarine cream can then be ripened with starter cultures in the same way as butter cream and when ripe churned in the conventional butter churn, or the starter can be added to the margarine cream immediately before churning. A margarine churn of this type is shown in Fig. 40. The cream after being cooled is pumped into the churn which is then rotated at "churning speed"; the fat particles aggregate and form grains, and when these are of suitable size, 1–3 mm, the surplus milk is drained off. As the churn is provided with three pairs of kneading rollers inside, the solid fat granules can be worked together into plastic masses and kneaded to the right moisture content. As about 80 per cent of the original milk is drained off as a by-product from the churn and in most cases cannot be re-used for the same purpose, the process is costly and labour-consuming, unless some special profitable usage can be found for the by-product; the process has therefore been used mostly in places of high butter production where skim milk was cheap, and now and then patents have been taken out for minor modifications of the principle. Quite recently a similar process has been the subject of an American patent [155] which claims to produce a margarine of better consistency, texture and appearance than that made by the more usual methods. The fat, for example semi-hydrogenated cottonseed oil of 36°C melting point and 28°C setting point, is heated to about 48°C and pre-mixed with ripened or unripened milk in the proportion of 25–45 per cent fat to 55–75 per cent milk. The mixture is passed into a tube where steam under pressure is blown in through jets in the direction of the flow, while in the tube a pressure of about 15 lb is maintained. The condensing steam heats the mixture, and by vibration and impinging on the fat causes this to disperse in finer globules in the milk. The emulsion thus formed is forced through an adjustable orifice plate, which helps to maintain back pressure, and into a vacuum chamber held at a vacuum of about 25 inches. The sudden release and change of pressure causes further dispersion and stabilization of the emulsion. It is claimed that the size of the fat globules are of the order of 2-5μ. The emulsion is now cooled to below the setting point of the fat, as is cream for butter making, by any conventional method and the cooled cream churned in the usual type of butter churn, for example as shown in Fig. 40. It will be seen that after the emulsion is formed the process follows closely that of butter factories, and use of steam and dispersion into vacuum resembles the method in the "Vacreator" plant. Phase inversion from cream to margarine takes place in the churning process, and the large excess of milk separates from the margarine, which retains 14–16 per cent moisture and about 0·7–1 per cent milk solids. The segregated margarine can now be washed with water for removal of loose adhering milk particles and can be salted and kneaded in the usual manner. The cream-type of emulsion formed in this process by steam impingement and spray dispersion instead of the more usual emulsification and homogenization is rather thin, 25–45 per cent fat, and a large quantity of spent milk is obtained as a by-product; this can be used for various purposes, but would hardly appear suitable for re-use in the process after the physico-chemical changes it has undergone. No information is available about the fate of aroma substances from the milk when submitted to the vacuum.

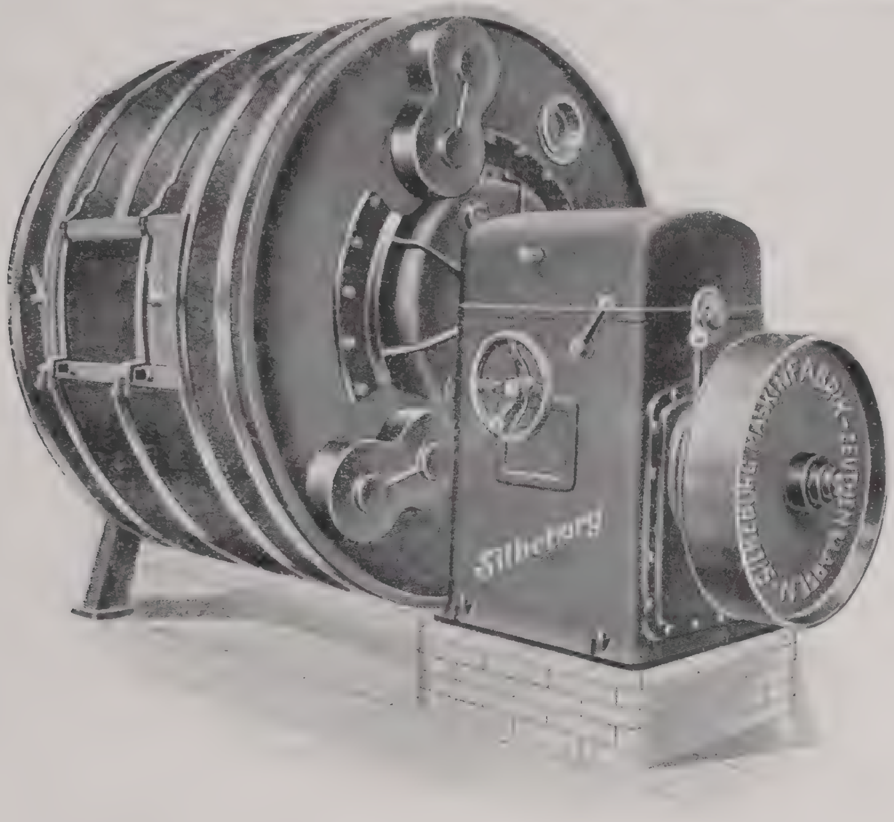


Fig. 40. Silkeborg rotary churn for margarine
(Courtesy: *Silkeborg Engineering Works*).

In all the emulsification processes described so far the phases have been mixed and emulsified in liquid form for subsequent, generally rapid, solidification of the emulsion. There are, however, some manufacturers who prefer to work with the fats in the solid form when emulsified with the aqueous phase. There are several variations of that method. Sometimes the whole fat-blend is kneaded and plasticized to soft consistency in a machine of the vacuum blender type, see page 210, and the aqueous phase then gradually added and kneaded in. Water-soluble ingredients and emulsion stabilizers are dissolved in the aqueous phase, and if any fat-soluble additions have to be made they are first dissolved in 1–2 per cent liquid oil. Or if the blend contains several fats of different consistency, the individual fats are separately worked to the same consistency and then kneaded together, the liquid oil finally being worked into the solid fats before the process is completed by the gradual addition of the aqueous phase. This cold method gives a moisture dispersion more in the form of films and irregular drops or lakes in contrast to the generally globular dispersion by the liquid emulsification process.

The reasoning advanced for this cold mixing process is the saving of the cost of melting and subsequent cooling and solidification of the fats, their potential loss of quality by heating above melting point temperature, the advantage of using the existing crystalline structure of the fat, modified only by mechanical working, instead of introducing new crystallization phenomena and uncertain structure stability caused by the polymorphism of many of the glycerides. While some of these arguments might apply to a few fats used without refining, such as oleo and neutral lard, practically all fats now-a-days are refined at high temperature, and even oleo and lard are rendered in liquid form. The plant for the cold mixing process is, of course, extremely simple, but handling charges are relatively high and it seems difficult to achieve a smooth texture and regular consistency owing to the incidence of thixotropy during working.

Processes in which emulsification takes place at the same time as solidification and plasticizing, as is the case in the tubular cooling plants, will be described later, in the chapter on Continuous Processes.

Cooling and Crystallization of the Emulsion

1. THEORY AND PRACTICE. REFRIGERATION

With very few exceptions the margarine emulsion is submitted to "shock" cooling and rapid solidification, partly to fix the emulsion by the mechanical restraint to separation in the solid state, and thus aid the effect of the emulsion stabilizers, partly to ensure the correct type of crystallization of the solid glycerides to obtain the desired consistency and smooth texture. The exceptions are, for example, in India where the imitation product Vanaspati of the native butter Ghee is usually wanted with a granular texture, and in certain other districts where a grainy lard-like texture is preferred.

The descriptions, consistency, texture and plasticity are sometimes used synonomously; they are here used to indicate different features. Consistency is a property describing a smooth, even, plastic state, varying from very soft like petroleum jelly, via soft, medium, firm, tough to hard and brittle;

in all cases the sensation on the palate is of smoothness; consistency is temperature-dependent. Texture indicates the state of structure and varies from smooth to mealy or floury, grainy, granular or sandy to coarse and lumpy. Plasticity is associated with both terms, as smooth as well as grainy and coarse plastic products are found.

With the few exceptions mentioned margarine is required to have a smooth texture and a medium consistency when intended for table use. When used for various confectionery and bakery purposes a smooth texture combined with firm or tough consistency is demanded.

The term "spreadability" is often used in connection with the solid state of butter and margarine which are mostly used for spreading on bread, and the term is sufficiently descriptive to indicate the property. It is connected with consistency and shear, but is also influenced by the medium on which the product is spread. Texture has little influence on spreadability.

Consistency, texture and spreadability are very important properties of margarine, not only through their physical effect, but also their physiological and psychological effect on flavour and general palatability. The total result of these physical properties is the summation of the influence of glyceride composition, state of emulsion and type of crystallization of the fat. The first two features have been dealt with in earlier chapters; the crystallization problem is largely a task for the cooling and solidification process, but is also influenced by mechanical working during and after solidification.

As mentioned on page 20 the natural fats and oils consist of a number of, mostly mixed triglycerides, all of which melt and crystallize at different temperatures, some even at several temperatures because of their polymorphism. When several fats and oils are blended, which is usually the case with margarine fat-blends, the number of glycerides is increased and the melting and crystallization phenomena are more involved and often further complicated because of inter-solubility of some of the glycerides. If a molten blend containing a large number of different glycerides is allowed to cool very slowly, crystallization is gradual according to the setting points of the individual glycerides and macroscopical crystals are formed by the solid glycerides, leading to a granular texture. Rapid cooling leads to formation of microscopical crystals and smooth texture and this is further assisted by stirring during cooling. Instantaneous or "shock" cooling gives a smooth texture without stirring. There are, however, exceptions to this general statement, if the fat-blend contains only 2–3 glycerides of great similarity or of extreme physical differences.

The consistency characteristics of margarine are related to the ratio of solid and liquid glycerides present at any particular temperature, which can be measured by the melting dilatation. As mentioned on page 54, in temperate climates a suitable consistency is generally obtainable, if the proportion of solid glycerides at 15–20°C is about 20–25 per cent. Cooling and solidification of the margarine emulsion requires, however, not only extraction of heat to ensure solidification of the preferred proportion of solid glycerides, but cooling of the whole emulsion to temperatures as low as 2–3°C with ice-water cooling, and far below freezing point with the dry cooling system to reach the degree of supercooling which in many cases is necessary to obtain the right crystal size and formation. The amount of refrigeration needed for that purpose depends on the glycerides present and their degree of saturation. The heat of fusion or crystallization for saturated simple glycerides of the type that may be present in margarine blends, and in the most stable form, are:

Trilaurin . . .	46·2 cal. p.g.,	46·3°C m.p.
Trimyristin . . .	50·3 ,,	57°C ,,
Tripalmistin . .	53·1 ,,	65·7°C ,,
Tristearine . . .	54·5 ,,	72·5°C ,,

Mixed saturated glycerides of the same acids would be of proportional order. Triolein has a latent heat of crystallization of 29 cal. p.g., the melting point being 5°C. Trilinolein and trilinolenin with melting points −13°C and −24°C respectively are hardly affected at the temperatures used for solidifying margarine emulsions, but the mixed saturated-unsaturated glycerides make some demand on refrigeration for crystallization, according to their degree of saturation. As examples may be mentioned cottonseed oil, I.V. 108, semiliquid at 0°C, which has a crystallization heat of 20·6 cal. p.g.; when hydrogenated to an I.V. of 59·5, when it is a plastic fat, its crystallization heat is 27·4 cal. p.g., and when hydrogenated to very hard consistency, and consisting nearly entirely of palmito-distearins, the melting point is 62·3°C and the heat of crystallization 44·3 cal. p.g. [156].

The quoted figures for heat of crystallization apply to the change from complete liquidity to the solid state, but in mixed margarine blends some of the glycerides are not solidified at the temperatures of crystallization used in the industry, for example, mixed oleo-linoleins and more unsaturated glycerides, others are temporarily crystallized and re-melt when temperatures rise on release of supercooling heat or when heated during maturing, stabilizing of crystals and plasticizing. As already mentioned, only 20–25 per cent solid glycerides should be present in table margarine at room temperatures.

In addition to extraction of heat of crystallization, cooling is also required for bringing the emulsion down in temperature from that ruling when discharged from the emulsification plant. To calculate these requirements it is usual to reckon the specific heat of the fat-blend as an average of 0·5, although there is a slight variation with temperature and composition, and that of the aqueous phase as 1–1·2 according to whether salt is present or not. Heat of crystallization for the aqueous phase may mostly be ignored. In practice, is has been found that an average refrigeration demand of 28,000–30,000 Cal. per ton emulsion is suitable for overall calculation. The actual demand is, as will be explained later, adjusted for individual blends and emulsions from observations during manufacture. The figure mentioned applies only where refrigeration and solidification is effected by the direct ammonia expansion method. A further 10 per cent should be allowed, if solidification is by the dry method via ammonia-cooled brine. When solidification is by the ice-water method, the requirements are much higher as much of the cooling power is dissipated through the wasted effluent ice-water and may be as high as 80,000–100,000 Cal. per ton, metric.

Solidification of the fat-blend is a crystallization, or part-crystallization, process, and to give the best results for the subsequent development of a good consistency and smooth texture great care must be taken to achieve the right kind of crystallization; the process must therefore be adjusted to some extent to the fat-blend or glyceride composition. The solid plastic margarine is built up of a large number of small crystals of solid glycerides which form a skeleton enmeshing the liquid glycerides. The change from the liquid to the solid state of the emulsion should be rapid enough to ensure that the crystals formed are of microscopical size as macroscopical crystals give a granular texture to the product. The "shock" cooling processes adopted in the manufacture usually ensure this fine crystallization, if contact of the emulsion with the cooling medium quickly reduces the temperature of the former to 3–4°C or less. In the dry cooling process on refrigerated surfaces, which is now the most common, the crystallization contact temperature is generally well below −10°C and gives rise to a good deal of supercooling. At the low temperature of solidification the ratio of solid to liquid glycerides is higher than at the temperature at which the margarine is required for use, and the product is therefore much firmer, but it is not the ratio alone that determines the hardness or softness of the consistency; it is also to some extent the crystal size. If the fat consists of a too large number of excessively small crystals the structure is too close, and by reduction in the size of the capillaries between the solids and more interlocking of the frame work the movement of the solids in the viscous liquid is made less easy, and plasticity is reduced. The formation of excessively small crystals is likely to occur if solidification takes place during rapid stirring; the higher the speed of agitation and the lower the temperature the smaller the crystals, and a margarine with the correct solid-liquid ratio of the glycerides may at the material temperatures be too hard because of the excessively fine crystal formation. This excessive fineness is largely avoided by the technique of nucleus formation, which has been referred to under churning technique. As the temperature is lowered, crystallization does not take place at the same time throughout the whole mass, but at certain points where crystallization centres or nuclei are formed; this formation can also be initiated by "seeding" material, as described in some procedures for churning. Nucleus formation, whether during temporary lowering of the churning temperature or by super-cooling the emulsion for solidification, does not usually persist indefinitely, but reaches a maximum. The restraint on mobility of the formed crystals by the increasing viscosity of the liquid during cooling down tends towards formation of larger crystals round the nuclei, unless this trend is disturbed by excessive stirring. Once formed, the nuclei persist as centres for crystallization during temperature changes, and the fat can be heated to even a few degrees above the melting point and still retain these microscopical nuclei as centres for development of larger microscopical crystals when the product is cooled again. The important points in connection with the solidification of the margarine emulsion, in order to obtain a good basis for a suitable consistency and plasticity as the result of post-cooling treatments, are therefore either to initiate during the emulsification process a crystal nucleus formation by suitable cooling followed by slight re-heating under moderate stirring, until the discharge temperature from the churn is reached, which treatment will preserve the nuclei for subsequent crystallization, or to supercool the emulsion in the dry cooling process to a degree, which will develop the required nucleus formation, so that the solidified emulsion, when left quiescent while the temperature rises as the result of past-cooling crystallization, allows this to take the course of growing larger microscopical crystals round existing nuclei, together with formation of fresh smaller crystals. The sizes of the microscopical crystals vary somewhat with the composition of the solid glycerides, but should be of the order of a few thousands of a millimetre, for example 3–10μ, with appropriate size frequency distribution. The finer the phase dispersion in the emulsion the more the tendency to an excess of the smallest size. Formation of too large crystals, of macroscopical size and giving grainy texture, may sometimes "loosen" the emulsion. The nucleus formation during supercooling can be influenced by cooling intensity, such as the temperature of the refrigerating surface, the thickness of the layer of emulsion exposed to it, the period of exposure, etc. A combination of the two methods of nucleus formation, namely during emulsification and by supercooling, is also used and often is found very advantageous.

Owing to the large number of variations in the glyceride composition of margarines, because of the wide choice of fatty raw materials for the blends, and in the cooling systems used, as well as in manufacturers' and consumers' preference for consistency firmness in the finished product, hard and fast rules for cooling procedure are difficult to indicate, but in general it can be said that margarines with fat-blends, which have steep melting dilatation curves, i.e., a short melting range, require more intensive cooling than those with flat curves; the intensive cooling is also preferable for fats which by natural setting form a coarse crystalline body.

The introductory chapter on the history of margarine mentioned that the earliest cooling method consisted in pouring cold water into the churn after emulsification; later the emulsion was run into a basin with cold water. This answered the purpose where sufficiently cold water was available and when oleomargarine, as was then the rule, was the fat. In some places and at certain seasons ice had to be used for cooling the water. When more heterogeneous fat-blends were introduced, a large quantity of cold water was sprayed on to and mixed with the emulsion, as it flowed from the churn to a sloping trough, and the mixture of cold water and solidifying margarine was collected in a wagon or basin, while solidification was completed and the water drained away. This wet method is still in use in some works, except that since refrigeration plants were developed the spray of cold water is kept constantly at 1–2°C, and the quantity is varied according to crystallization requirement. Fig. 41*A* shows a diagram of this system.

The first dry cooling system which found wide industrial application was the double-drum system shown in Fig. 41*B* in which the emulsion was sprayed by means of a perforated distributor pipe into the trough formed between two parallel hollow cylinders *R* of equal diameter and set close together; they rotate in opposite directions and brine circulates through them; the solidifying emulsion, squeezed into a thin film, is carried to diametrically opposite points *P* and removed by scrapers as thin flakes or sheets and collected in wagons *W* placed underneath.

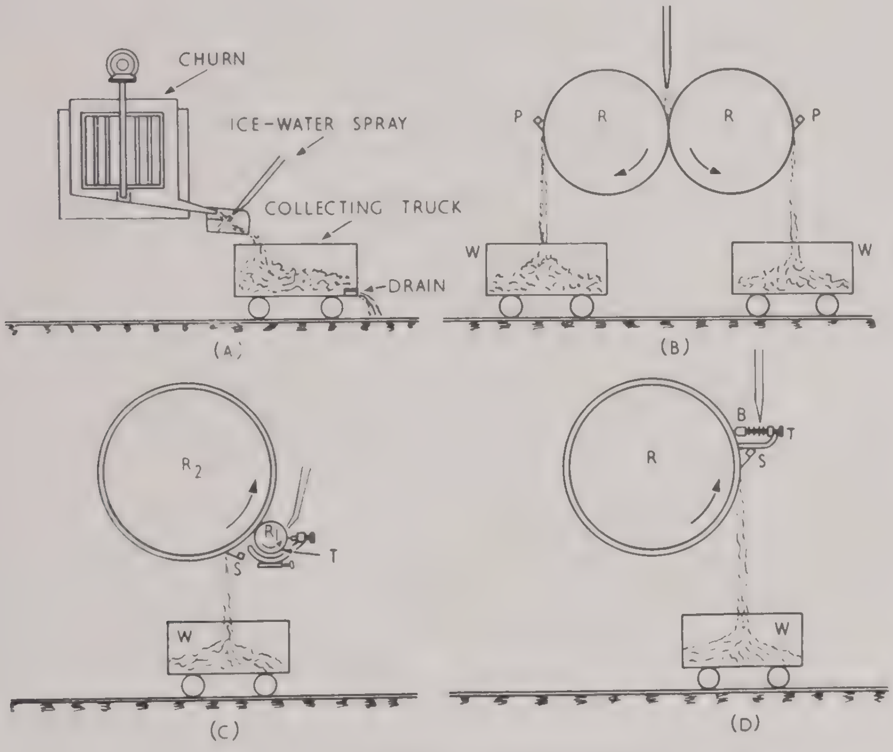


Fig. 41. Diagram of cooling systems.

A few years later the single-drum system was evolved; it utilizes a higher proportion of the drum surface for cooling and has now displaced the double-drum system in many factories. The emulsion can be applied to the surface in various ways. Fig. 41*C* shows diagrammatically the use of an application or feeding roller. The emulsion is pumped to a jacketed trough *T* where it is picked up by the small roller R_1 dipping into it and revolving in the same direction as the large one R_2, but at a much higher speed. The small roller, which is not cooled, smears the liquid emulsion on to the refrigerated surface of the large roller, where it solidifies while being carried round to a point just below the feeding trough and is removed as a solid thin sheet by a scraper *S* and dropped into a wagon *W* below.

Another system of applying the emulsion to the refrigerated roller surface is shown in Fig. 41 *D*. The trough *T* is at the side of the roller *R*, the cylindrical surface of which forms one side of the trough; the walls of this can be warmed to prevent the emulsion solidifying. An adjustable bar *B* above the trough regulates the thickness of the layer, which the roller picks up, and a scraper *S* underneath the feeding point removes the solidified sheet of emulsion. In another arrangement the feeding trough is at the top of the roller and the emulsion is distributed on it through a narrow slit, the gap between trough and roller regulating the thickness of the layer.

There are several variations in the solidification plants of the refrigerated roller type; some of these will be described in greater detail in the next chapter.

The closed dry cooling systems in which the emulsion is chilled and more or less solidified by passing under pressure through narrow channels or annular spaces along or between refrigerated surfaces will be described in connection with the plants employing them in the continuous manufacture, combining emulsification, crystallization and kneading.

For producing the refrigeration, ammonia compressors are now mostly used in margarine factories; both compression and evaporation pressures are moderate and suitable for all climates.

In the wet cooling system cold water of 1–2°C is used in a pressure spray and special constructions of the emulsion-cold water contact zone are adopted to ensure intimate mixing for quick cooling. The cold water, often termed ice-water, is cooled in an ice-water tank of sufficient capacity to cope with the maximum demand, as too high temperature of the water leads to granular crystallization. The "spent" ice-water which is drained away from the solidified emulsion should not be used again owing to the danger of infection, resulting from contact with the aqueous phase of the margarine; it can, however, be used for pre-cooling the fresh water in a heat-exchanger prior to refrigeration. It is customary to use a buffer storage tank for ice-water, separated from the tank where the evaporation coils for the refrigerant are placed, as this provides resiliency in the demand on the compressor; different margarine compositions require different quantities of ice-water. By the wet process the crystallization temperature of the emulsion is usually 5–7°C.

The refrigerant in the dry drum-cooling method in the "indirect" ammonia system is salt-brine or calcium chloride brine. This is drawn by centrifugal pumps either from evaporator coil tanks direct or from brine storage tanks; brine returning from the cooling drums is taken back to the evaporator tank and should not during circulation increase in temperature by more than 2–3°C; the circulation system should be dimensioned accordingly, as otherwise irregular crystallization may occur. The temperature of the brine at the cooling drum inlet is generally not more than −12°C, preferably −15°C, but is often adjusted according to the fat-blend. If the brine is made with ordinary salt the minimum temperature in practice would be −15° to −16°C to avoid freezing; with calcium chloride brine of 22 per cent concentration a temperature of −20°C can be reached. If the brine temperature is −15°C, which is the most common, the evaporating temperature of the ammonia in the coils should with well-kept and properly dimensioned coils not be below −20° to −22°C, corresponding to an evaporation pressure of about 1·9–1·7 atm. abs. With brine inlet and outlet temperatures of −15° and −12°C respectively the contact temperature of emulsion and cooling surface is about −10° to −12°C; the average temperature of the solidifying mass depends on the thickness of the layer on the drum and the speed of its rotation. When coming off the drum in supercooled condition the solidified emulsion is usually −3° to −7°C, depending on glyceride composition, but it increases fairly quickly, in 5–10 minutes, to 5° to 6°C, as the delayed crystallization absorbs the supercooling.

In the "direct" ammonia system, which is the more common now, the evaporation of the ammonia takes place inside the cooling drum which thus acts as evaporator in the refrigeration system. This is the more rational and economic method, as it saves the efficiency losses by the heat transfer via brine, and the cost of installing and running the brine circulation system. It is more sensitive to sudden changes in the emulsion temperature, layer thickness and composition, but these variations can be coped with by appropriate arrangements and construction of the plant. With similar contact temperature as in the brine cooling system the ammonia can be evaporated at a slightly higher pressure, about 2·3 atm. abs., which increases the capacity and economy of the compressor. There are, however, still some manufacturers who prefer the brine circulation system as being more resilient and less sensitive to sudden changes in conditions.

One condition of successful crystallization on the cooling drum is the correct and even application of the emulsion to the surface; some of the methods adopted will be described later when dealing with details of the plants. Another condition is the removal by the scraper arrangement of the solidified emulsion in the correct condition of large thin flakes or continuous friable sheets. This is effected by a scraper fitted at an angle to the cylindrical surface. The chilling cylinder or drum is now mostly made of steel or special alloys of stainless steel or of steel clad with a layer of stainless steel or a coating of chromium; the latter metals have the advantage of being resistant to attack by the emulsion, if this contains salt or strongly acid milk. The scraper is generally a thin blade or a laminated blade, 0·5–1·5 mm thick, sometimes with chamfered edge which fits the curvature or the cylinder, and it is carried and backed by a rigid thicker plate or bar, through which adjusting pressure by means of springs or screws can be exerted on the blade, so that it fits close to the cylinder surface and scrapes cleanly.

The back-plate rests in bearings and can be hinged or slided back to permit easy change of blade. The thinness of the blade and the spring adjustment give it a certain resiliency and thus avoid excessive friction against the cylinder surface, and the material of which the blade is made should be slightly softer than the drum surface, as the pressure necessary for clean scraping causes a slight wear, in spite of the microscopical film of fatty substance adhering to the drum. The wear should be on the scraper as otherwise the drum becomes scored, which soon leads to uneven cooling and necessitates costly re-grinding, but a material should be chosen that lasts well without scoring, to avoid too frequent change and re-grinding of blades. Steel and stainless steel scraper blades are used where their hardness permits it. From the mechanical point of view gunmetal, bronze and copper blades are preferred in many factories because of their better performance. There is however some possibility of the abraded material getting into the margarine, and although the proportion is so small that it is well below 1–2 p.p.m., at which level copper begins to exert some practical action as oxidation catalyst, there is often a potential risk, particularly with salt and acid ingredients in the emulsion, even if at the low temperature the rate of reaction is slow.

The angle between the blade and the tangent of the cylinder surface at the point of contact is usually 15°–35° and can in some cases be adjusted by the distance the blade projects beyond the back plate. The optimal angle depends to some extent on the peripheral speed of the drum, which again depends on the diameter and speed of rotation, that varies with the different constructions from 7–70 r.p.m. Some are set to revolve at a fixed speed, but it is a great advantage to use variable speed motors for driving the cooling drums, as that gives a further method of adjusting the degree of cooling to the composition of the fat-blend, in addition to variations in the thickness of the emulsion layer, for which all plants make provision. Too wide contact angle between scraper blade and drum surface entails the risk of the solidifying sheet of emulsion rolling up in compact small cylinders at the contact line, particularly with thick scrapers with blunt cutting edge.

2. CRYSTALLIZATION AND SOLIDIFICATION PLANT

Wet Process.—Although the dry cooling process is now used in most factories, there are still some manufacturers who employ the older wet process and strongly hold the opinion, that it is the most suitable for production of high quality margarine. In some factories the dry process is used for table and household margarines, whereas the wet process is preferred for bakery qualities of very firm or tough consistency, based on fat-blends with high-melting animal and hydrogenated fats. It is claimed that the waxy glossy texture and appearance of these qualities can best be obtained by the type of crystallization induced by wet cooling and modified by subsequent maturing at room temperature prior to kneading and working.

For wet cooling the discharge temperature from the churn should preferably be as low as possible, consistent with the setting point of the margarine, partly to induce in the churn a good formation of crystal nuclei as there is very little supercooling by the wet process, partly to minimize through the high viscosity of the thick emulsion the washing away of ingredients in the aqueous phase by the large quantities of ice water.

Some loss of fat and milk cannot, however, be avoided and the extra amount of milk which is therefore needed is one point of criticism of this method. Another is the potential danger of infection of the margarine from the cooling water, as it is not practicable to sterilize such large quantities of water. Unless water of great purity is available micro-organisms, which may not be able to develop at the low temperature in the water, may find a favourable substrate for growing, when absorbed in the margarine, thereby causing premature staleness.

As the amount of ice-water used is 5–8 times that of the emulsion cooled, and as it should preferably be as cold as 1°C, much of the refrigeration energy is lost by the water running away to waste as it cannot be re-used. In many cases it is not practicable to recover some of the energy through heat-exchangers, as the water entrains some fat which, though small in amount, may interfere with heat transfer by forming films and deposits on surfaces. To trap this fat which is generally mixed with milk-solids elaborate settling and trapping tanks for the effluent are essential. Some 60,000–80,000 Calories or more must be extracted from the water for cooling one ton of margarine, but as the evaporation of the refrigerant is at about −6°C the capacity of the ammonia compressor is much higher than when working with evaporation at about −20°C.

Qualities based essentially on coconut or palmkernel oil are usually cooled in the churn to 22–24°C before discharge and are crystallized with 5–6 times the amount of ice-water of 1–2°C. Churnings with oleo, lard and premier jus, if of table quality, might be discharged at 26–28°C and cooled with 6–7 times the amount of ice-water. Pastry type margarines with high melting point are discharged from the churn at 50–60°C. Qualities made predominantly with semi-hydrogenated fat are run off at 28–30°C and cooled with 7–9 parts ice-water.

Solidification takes place usually in a sloping trough of various constructions, where the emulsion flowing or pumped from the churn is spread as a flat ribbon and douched with a spray of ice-water, which is supplied under a pressure of 1·5–2 atm. as a sheet that cuts the ribbon of emulsion at an angle, breaks it up and solidifies it as pearl-like granules. The trough is generally provided with a box-like chamber where the emulsion-ice-water contact takes place; from there the mixture of granules and water runs down the chute to separation boxes or trucks.

Fig. 42 shows a sketch of a crystallization box for ice-water cooling. From the churn *A* the emulsion flows or is pumped to the outflow box *B* and through an adjustable slit *C*; the height of this regulates the thickness of the ribbon which is formed when the emulsion overflows into the whirlpool *D*, where it is cut and broken up by the spray of ice-water from the pipe *E* that ends in a flat nozzle piece *F* which delivers the cooling water as a pressure-spray or fish-tail shaped sheet. The emulsion and the water are thoroughly mixed in the whirl-pool and the solidified granules and the water flow along the discharge chute *G* to the outlet *H* and the separating arrangement for the water. The ratio of emulsion to ice-water is usually regulated by the thickness of the emulsion ribbon passing slit *C*, about 1 in. for medium cooling, less for strong cooling, but can also be adjusted on the water supply.

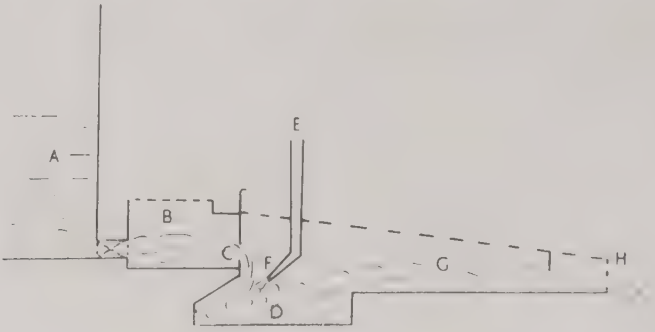


Fig. 42. Crystallization box for wet cooling.

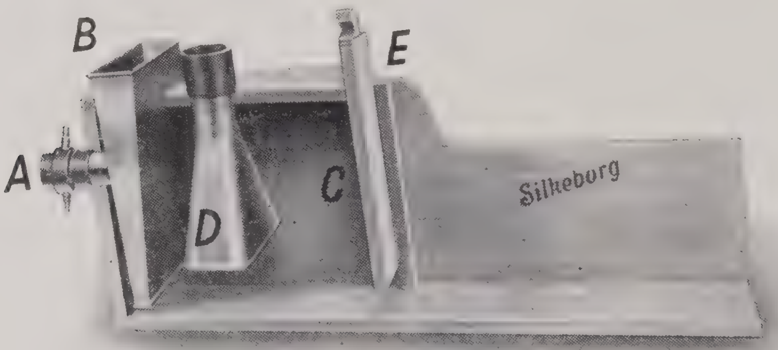


Fig. 43. Crystallization box for wet cooling (Courtesy: *Silkeborg Engineering Works*).

A slightly different construction of a crystallizing box is shown in Fig. 43. The emulsion enters through pipe *A* the distributor box *B* where it is spread on the bottom of crystallization box *C* and douched with ice-water from spray nozzle *D*. The mixture of margarine granules and ice-water is drained off under the adjustable dam *E* to trucks.

As the temperature of the emulsion-ice-water mixture is 5–6°C, the crystallization is not so rapid as with the dry process, and it is advisable to keep the emulsion granules in contact with the ice-water for a few minutes, for example by running the mixture into crystallization trucks or wagons of which there are various types. The earlier and cheaper form was usually made of hardwood, beech or other non-odorous wood of close grain, but nowadays aluminium or stainless steel are preferred materials as they are easier to clean and sterilize and therefore offer less risk of being a source of infection. The trucks are provided with an overflow or draining arrangement for the ice-water which sinks to the bottom while the solid margarine granules float on the top. The contact time while the water drains off during the filling of the truck suffices for completion of the solidification, but it is an advantage to leave the granules a few hours at room temperature to stabilize the crystallization before the next step in the process. The product from the wet process usually contains an excess of water loosely held, which has to be worked out in later treatment.

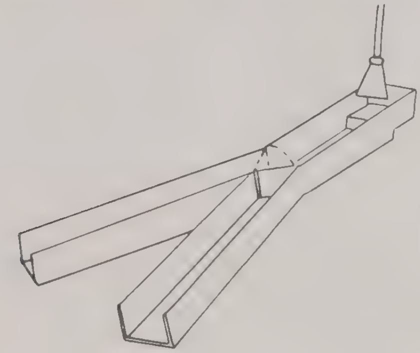


Fig. 44. Run-off gutter for wet cooling.

If, as is often the case, the contents from one churn will fill two or more trucks, and to avoid the latter being too unwieldy in size for manual handling, crystallization boxes are sometimes arranged with two outlet chutes which can be used together on two trucks or alternately by means of a guide plate, as shown in Fig. 44.

Figs. 45 and 46 show two designs of crystallization trucks which are often used. The truck in Fig. 45 is a rectangular box with vertical sides and ends.

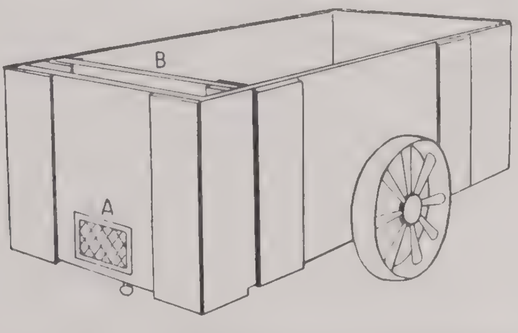


Fig. 45. Crystallization truck for wet cooling.

At one end is a square opening *A* covered by a strainer plate, through which the water drains away. A wooden partition wall *B*, supported by wooden channels on the sides, reaches nearly to the bottom and allows the water to reach the drainage chamber while retaining the granular margarine. The two wheels carrying the weight are rather large for easier manoeuvring and lesser wear on the floor. The truck in Fig. 46 has the wooden partition in one corner and the partition is provided with a handle so that it can be lifted slightly to allow the water to reach the strainer plate when the truck is filled to an adequate level. One end is sloping to facilitate emptying of the truck by shovelling.

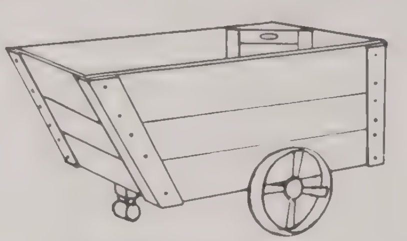


Fig. 46. Crystallization truck for wet cooling.

In large installations for wet cooling the emulsion-ice-water mixture is sometimes run into large aluminium or stainless steel hoppers shaped as an inverted truncated pyramid or cone, the bottom of which is a large slide-valve shutter. Some ice-water is first run into the hopper with the bottom valve closed, and then the mixture. While the hopper fills up the water is drained away and finally a truck is placed underneath the hopper, the slide opened and the contents dropped into the truck. In such large installations the trucks are frequently on rails or constructed as boxes to be transported by lifting platform trucks. Fig. 47 shows a sketch of such an installation.

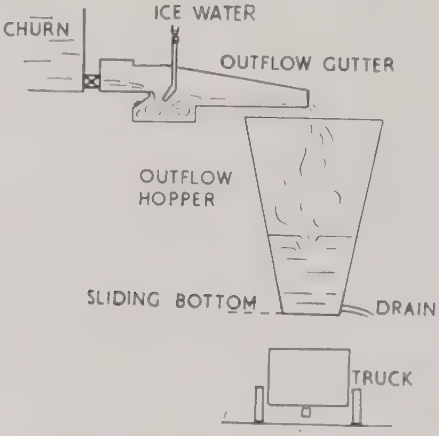


Fig. 47. Sketch of outflow hopper for wet cooling.

In addition to the disadvantages of the wet process which have already been mentioned (namely the large demand for bacteriologically clean water, the waste of a large proportion of refrigeration power and the loss of material through the effluent water, which loss in many installations amounts to 0·5 per cent of the fat or more) there is also the drawback of wet floors and a very humid atmosphere in the process department, a condition very favourable to mould growth. Furthermore, the solidified product contains an excess of moisture which must be worked out in rolling and kneading processes. The moisture content of water-cooled emulsion is often as high as 30–35 per cent, and if the blend contains fat of high water retaining power, or if good emulsion stabilizers are used in the churning process, difficulties may at times be experienced in removing excess moisture without overworking the margarine and damaging the consistency. Much of the moisture from the ice-water cooling is, however, loosely held as coarse droplets, provided the water temperature, the emulsion closeness and the water:emulsion ratio are correct, and such loose water largely drains away during the period the solidified granules are held in storage prior to kneading. For this reason, as well as for completion and stabilization of crystallization, wet-cooled margarine emulsion should be stored some hours before the next treatment, the period depending largely on the composition of the blend, 3–4 hours with vegetable fat blends, but longer with animal and hydrogenated fats.

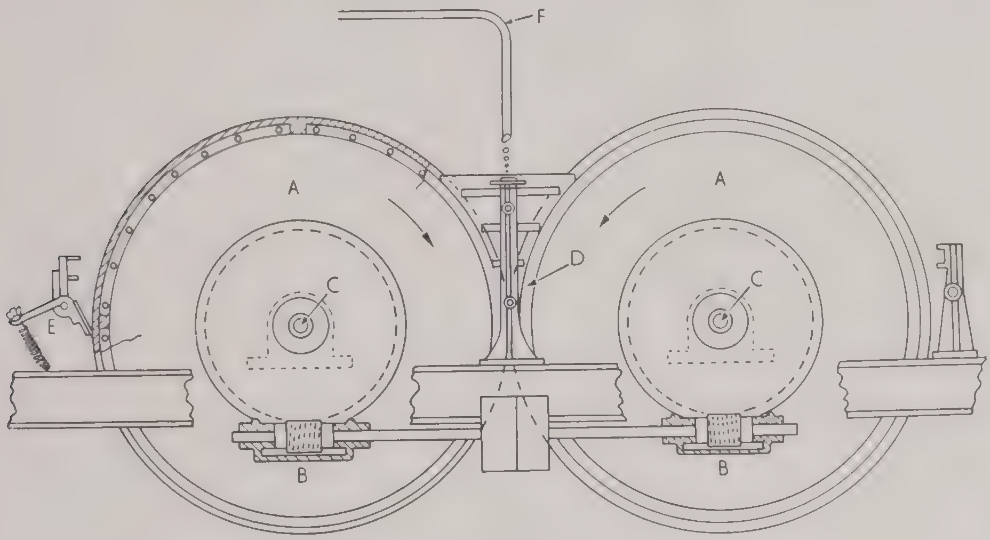


Fig. 48. Schou double-drums for crystallizing margarine.

Plant for the Dry Cooling Process.—Although the single cooling drum system, as used, for example, in U.S.A. for chilling lard or shortening of the compound lard type, had been tried for solidifying the margarine emulsion, the crystallization conditions with margarine fat-blends and emulsions were so different that no success in practice was achieved until Schou invented his double-drum system in 1907 [157], shown in diagram Fig. 41*B*. The plant consists of two parallel steel drums, originally cast steel, with a very finely ground smooth surface. Calcium chloride brine of about −15°C passes through an annular space in each drum in parallel, the speed of brine circulation being in accordance with the permissible increase in brine temperature and is regulated at the outlets *C* (Fig. 48) to ensure the drums being always full of brine and free from air pockets. The drums *A* rotate in opposite directions, driven through worm drive *B* by a variable speed motor. The distance between the drums can be adjusted by the slidable bearings and is usually 0·1–0·5 mm. The emulsion is pumped from churn or emulsifier through pipe *F* continuously to the trough formed at the confluence *D* of the drums and drawn into the narrow opening between them, where it adheres to the surface and is solidified while being carried round to the diametrically opposite point. It is here removed by spring-loaded scraper blades *E* as solid thin sheets or flakes and dropped into trucks or on to conveyor belts. Where the emulsion is supplied from churns working discontinuously on the batch principle, two or three churns are working together with staggered cycles of operation to ensure a continuous supply to the drums. It will be seen that the upper half of the drum surface is not available for cooling the emulsion. The standard size drum is about 6 ft. diameter and 7 ft. 6 in. long, and the output, according to the speed of rotation, of 6–15 r.p.m., and the thickness of the layer of emulsion, is 1–1·5 tons per hour. With the distance between drums, speed of rotation and rate of brine circulation being variable, the cooling and crystallization conditions can be widely varied, which was particularly important in the early days, when the knowledge of the chemico-physical nature of fats and emulsions was less developed than now and many new fats were being introduced. It is, however, advisable not to allow to large an increase in the brine temperature during circulation, in order to obtain uniform cooling; 2–3°C should be the maximum. With the described operating conditions the temperature of the solidifying emulsion just when leaving the drums is about −5°C and the product is in a supercooled state. Immediately after leaving the drum it increases a few degrees and in the trucks soon goes up to 5–6°C as the result of delayed crystallization. No loose moisture is visible, particularly when the aqueous phase is limited to 15–16 per cent. A slow rise in temperature continues during post-crystallization and stabilization, the extent depending principally on the glyceride composition of the blend. The product should preferably be left to rest during this period which may be two hours or more, after which the flaky friable material is ready for further treatment.

A few years after the introduction of the double drum system, cooling plants employing single drums, where nearly the whole surface was utilized for cooling, came into use, the liquid emulsion being applied to the cylindrical surface by various devices, as sketched in Fig. 41*C* and *D*. One of the plants which has found wide application is the Jurgens drum [158]. In the original plant calcium chloride brine was the cooling medium. A diagram of this plant is shown in Fig. 49 where *A* is the steel drum rotated by worm drive *B* at 15–16 r.p.m. Brine at −15°C enters at *C* and reaches through pipes or channels the annular space at the cylindrical surface on which the emulsion solidifies at a temperature of −8 to −10 C. The emulsion layer is applied to the surface of the big cylinder by means of a small rapidly revolving cylinder *F* at the side, which has the same direction of rotation as the cooling cylinder and is driven by chain drive from it. The feeding cylinder can be kept at room temperature or higher by circulating water entering at *G*, but usually no heating is required; it dips into a feeding trough *D* for the liquid emulsion from churn or emulsifier. This trough is jacketed, *E*, for circulation of water of a temperature suitable for keeping the emulsion in the correct state of fluidity. The layer of liquid emulsion picked up by *F* in trough *D* can be adjusted in thickness by the scraper device *H*, and the thickness of the layer applied to the cooling surface can be varied by adjusting the distance between feeding and cooling cylinders by means of the sliding bed, *I*. The emulsion layer on the cooling surface rapidly solidifies and is carried round nearly a full revolution until it meets a scraper blade of steel or other suitable material placed at *J* and falls off as a thin solid sheet in undercooled state, but the temperature soon rises to 6–9°C, depending on composition.

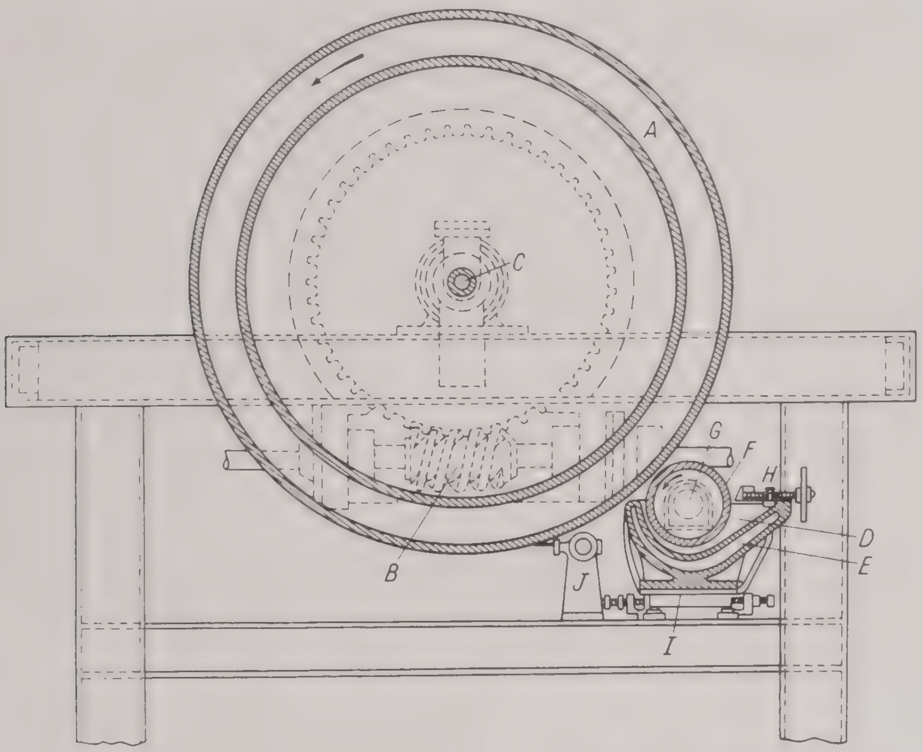


Fig. 49. Jurgens single drum for crystallizing margarine.

These drums are usually arranged to work at constant speed, the variation in cooling effect being obtained by varying the layer thickness. With brine at −15°C, speed of rotation 16 r.p.m. and the cooling cylinder 7 ft. 9 in. diameter and 7 ft. 6 in. long margarine made principally from animal fat or semi-hydrogenated oils are mostly solidified in layers of 0·3–0·4 mm, those made largely from coconut or palmkernel oils in layers of 0·5–0·6 mm. The output from drums of this size is 3–4 tons per hour, and they require 14–18 h.p. for driving. Smaller plants working on the same system are also used, but with smaller diameters the speed of rotation and the layer thickness should be adjusted to give adequate exposure to the cooling effect.

A slightly different arrangement for applying the emulsion is used in another make of brine-cooled steel drum. The feeding trough consists of a water-jacketed box, removable from the drum, but when fitted into position it is completely closed, the surface of the drum forming the fourth side of the box. It is fitted with a double-entry pipe for the emulsion and with an overflow pipe to convey excess emulsion back to a buffer tank, from which the emulsion is pumped to the box, and which receives the emulsion from the churn or emulsifier. The emulsion box is provided with a hollow-shafted paddle which keeps the emulsion well stirred; from a small water tank warm water of suitable temperature is circulated by pump to the jacket of the buffer tank, the jacket of the emulsion box and through the shaft of the paddle. The warm water is generally 2–3°C warmer than the emulsion, but with special high-melting qualities it may be 8–10°C warmer. The brine temperature is usually −12 to −14°C and to ensure uniform cooling from the whole cylindrical surface the increase in temperature of the circulating brine should be limited to 1°C, and the brine must therefore flow at high velocity. The scraper is fitted just below the feeding box, hence nearly the whole cylinder, surface is used for cooling. The drum is often arranged for variable speed driving, adjustable for 16–24 r.p.m. The thickness of the emulsion layer is controlled by the position of the feeding box, the setting of which is made by set screws and checked by "feelers." With qualities churned with a thick emulsion a layer of 0·25 mm is normally applied, with thinner and warmer emulsions the setting is finer, for example 0·15–0·2 mm. This type of drum is built in capacities up to about 4 tons per hour.

In another arrangement the feeding box has a jacketed side and bottom, the other side is formed by the drum surface and the top is open; the thickness of the emulsion layer is regulated by a heatable bar or pipe placed horizontally just above the box along the cylindrical surface; the slot between the drum and this bar can be varied, and any excess emulsion picked up from the box is removed and dropped back into it. In such arrangements a float in the box controls the inlet valve for the emulsion line.

The emulsion comes off the drum at a temperature just below freezing point and as usual soon warms up to 6–7°C. The thick emulsion forms usually large dry flakes, whereas the thin emulsion is taken off as practically continuous soft sheets of rather "damp" appearance.

The earlier drums were made of steel with the emulsion feeding box and buffer tank heavily tinned. Nowadays the cooling drums are often made of stainless steel or coated with a layer of stainless steel or hard chromium, and the auxiliary equipment is mostly of stainless steel. Sometimes the upper part of the cooling cylinder is covered by a shield of aluminium. Drums of different capacities, some as small as 0·25–0·5 tons per hour, and working on similar principles are built by a number of firms. In recent years, however, nearly all drums are constructed for cooling by direct expansion of ammonia in the drums, as will be described below.

Certain precautions are necessary to prevent the very cold cylindrical steel surface being damaged by moisture, which may condense on it during periods when the plant stands idle; with stainless steel the risk of corrosion is small. There is also a potential corrosion effect, if emulsion, containing salt and acid constituents, is left on the surface during prolonged shut-downs. When in operation the drum should be used continuously as otherwise ice will form on the surface and will damage or blunt the scraper knife. When at rest the drum surface should therefore be covered with a layer of fat or oil; groundnut oil is preferred because of its lesser tendency to oxidize and to freeze hard and flake off. When shutting down, brine circulation should be stopped when the buffer tank or the feeding trough for emulsion is empty; a small quantity of the oil is then poured into this tank, sufficient to cover the surface of the drum. When this oil appears on the drum the truck for collecting the solidified emulsion is removed and the scraper knife withdrawn from the surface; the drum is stopped when the whole surface is covered with oil. The emulsion box can now be drawn back from the drum and cleaned after removal of surplus oil. The drum surface itself is rarely cleaned, apart from a periodical wiping down and the cleaning by scraping off the oil layer when the plant is restarted. When this takes place brine circulation is started and continued for a few minutes to displace the warm brine in the drum while it rotates at slowest speed. The feeding box is placed in position and its warm water circulation started. The emulsion is now admitted to the buffer tank and the box, the scraper knife is applied to the drum surface and the layer of oil and a small quantity of solidified emulsion scraped off; this is collected separately and rejected. The truck is now placed in position to collect the solidified margarine.

It is essential to maintain a perfectly smooth and even surface on the drum to ensure homogeneous cooling; if in course of time, usually years, the surface is damaged through corrosion, wear from scraper or by the strain of temperature changes, it may be necessary to re-grind it; some manufacturers prefer to do this while the surface is kept cold by brine to ensure the right shape under cooling conditions.

The solidified emulsion from cooling drums shows no loose moisture, even if the product contains more than 16–18 per cent. water. The trucks for collecting it can therefore be of simpler pattern than those for wet cooling. For smaller installations the trucks are simply rectangular boxes, mostly nowadays of aluminium or stainless steel, on 3 or 4 wheels. In large installations where trucks may hold 1–2 tons each they are sometimes running on rails, sometimes they are boxes on low stands and transported by electric platform lifting-trucks.

Figs. 50 and 51 show some types of trucks much used in smaller factories. In the illustration of a drum installation in Fig. 54 are seen some of the large box trucks for transportation by electric accumulator platform trucks.

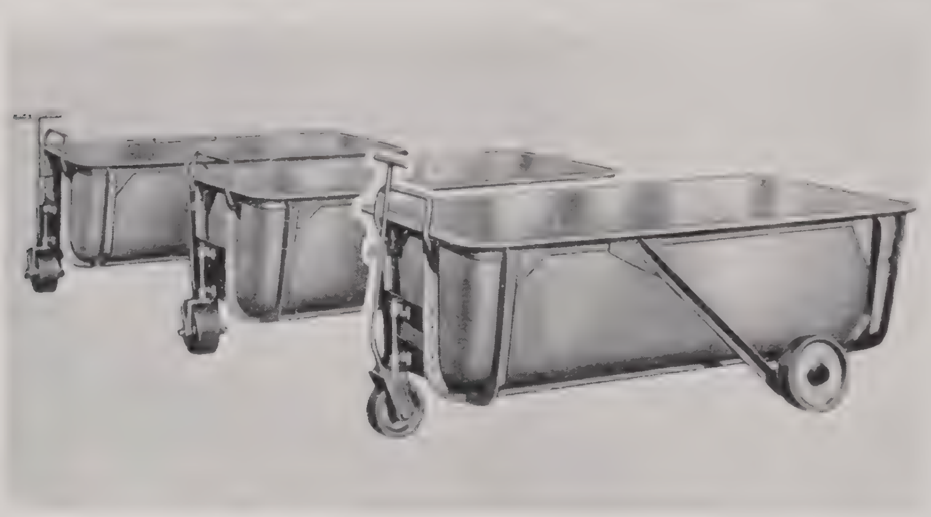


Fig. 50. Wagons for crystallized margarine (Courtesy: *A.P.V. Co. Ltd.*).

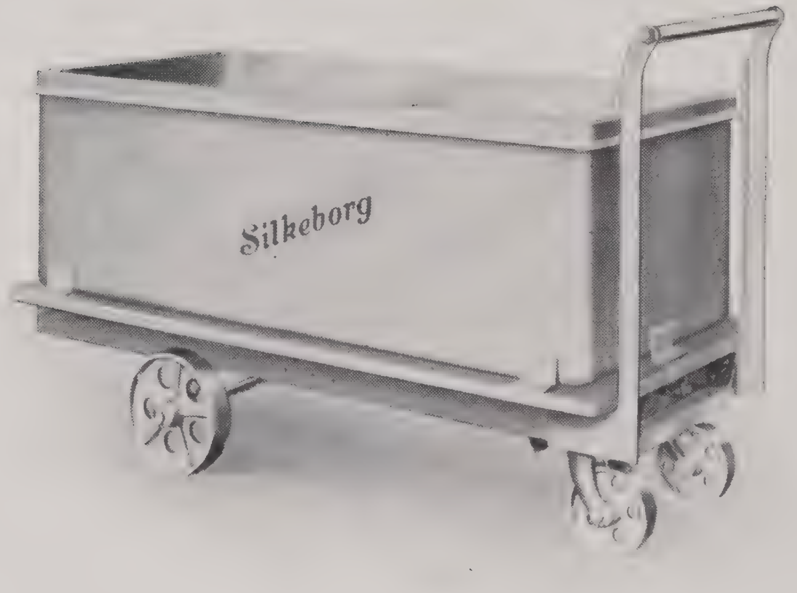


Fig. 51. Wagons for crystallized margarine (Courtesy: *Silkeborg Engineering Works*).

Although brine-cooled drums are still by some manufacturers considered easier to control and more resilient in effect than those cooled by direct expansion of ammonia in the drum, the latter have gradually become the more prevalent type since Naumann first patented it in 1928[159]. The difficulties of control and construction of the earliest plants were soon overcome and numerous installations of this type are now in operation, varying in capacity from a few hundredweights to 4–5 tons per hour. The advantage of this type of plant, compared with brine cooling, is the saving of refrigeration energy by avoiding double heat transfer, and the saving of brine tanks and circulation pumps, insulation costs, etc. On the other hand the ammonia circulation system is slightly more expensive. The evaporation pressure of the ammonia inside the drum is practically the same as that in the evaporation coils in brine tanks; hence the compressor capacity is not changed, but the cooling temperature on the surface of the drum is lower, the evaporation temperature of the ammonia being −20° to −22°C against a brine temperature of −14° to −16°C.

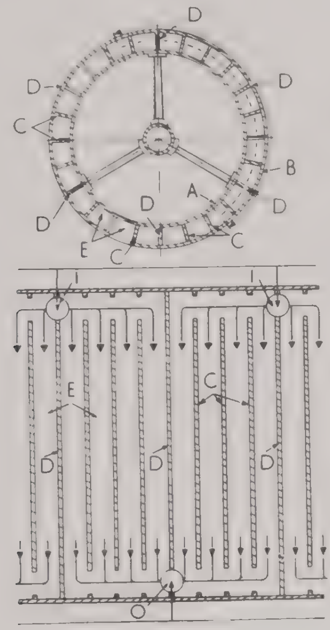


Fig. 52. Naumann cooling drum for direct ammonia expansion.

The Naumann drum installation is in appearance similar to the Jurgens drum (page175), and has the same kind of feeding trough, application roll for emulsion and scraper gear etc.; the cooling drum is, however, designed to utilize evaporating liquid ammonia as the cooling medium. As shown in the diagrams in Fig. 52, (*a*) and (*b*), the cooling drum is made from two concentric horizontal cylinders, the annular space between which forms the chamber in which the refrigerant circulates and evaporates. The two cylinders *A* and *B* are interconnected by longitudinal partitions or ribs *C* and *D*, cast in one piece with the cylinders; they lend strength to the structure, direct the refrigerant from inlet to outlet along the surface and assist heat transfer. The longitudinal passages *E* thus formed and uniformly distributed round the circumference of the drum are divided by the ribs in sections with inlet *I* at one end and outlet *O* at the other. Fig. 52(*b*) illustrates this in a development of part of the drum.

Fig. 53 gives a flow-sheet for ammonia circulation in this type of drum The liquid ammonia is supplied to the drum via a stop valve (*1*) and a regulating valve (*2*) in such quantities that when in operation the refrigerant space in the drum is approximately half full of liquid ammonia. The evaporation pressure which regulates the temperature inside the drum, −18° to −22 C according to requirements, is adjusted by a special valve (*3*) at the outlet from the drum. A trap (*4*) for liquid ammonia should be provided on the ammonia vapour line, so that only dry vapour returns via pipe (*5*) to the compressor; this trap, which has connections both to the suction side (*5*) of the compressor and via a regulating valve to the collecting tank (*6*) for liquid ammonia from the condenser, should contain a suitable quantity of liquid ammonia, and as it is under suction pressure it should be placed at such a level that the liquid can run by gravity from there to the drum.

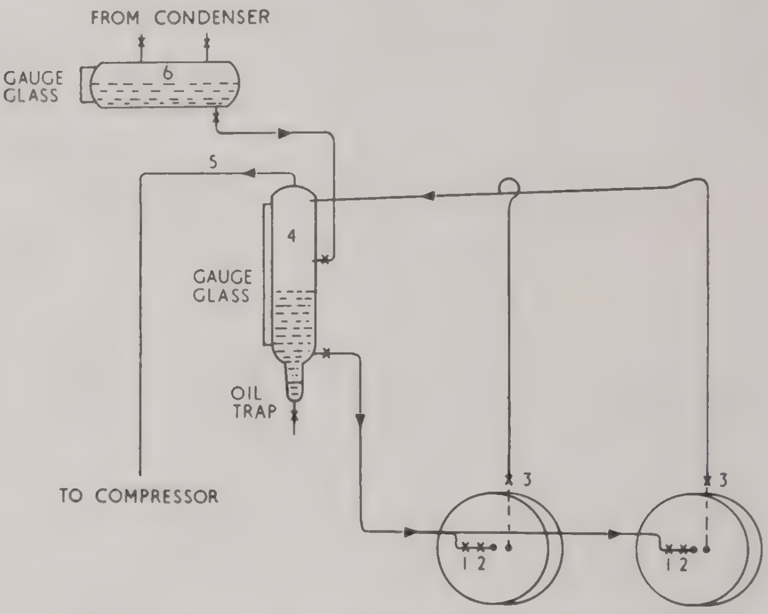


Fig. 53. Flow-sheet for ammonia for direct expansion drum.

These drums are of 4·5–5 tons per hour capacity, revolving at about 15 r.p.m. When shutting down the plant the ammonia inlet valve at the drum is closed shortly before the last emulsion is applied, to enable the liquid ammonia to evaporate and be withdrawn; the use of hot water to clear the emulsion must be avoided. The best procedure for closing down is to follow the emulsion with a layer of oil which is left on when the drum is out of operation. This is particularly important with steel drums, but also useful with those made from or coated with stainless steel or chromium. No warm water should be used for cleaning until the drum is at room temperature and emptied of ammonia.

Fig. 54 shows two drums of an installation of this type of plant. The left-hand drum shows also the feeding trough with the divided inlet from the emulsion pipe, and the top of the application roller. Under the drum platform can be seen the funnels through which the solidified emulsion in flaky form falls into rectangular aluminium transport boxes which slide into position under the drum on roller conveyors and are transported on electric platform trucks.

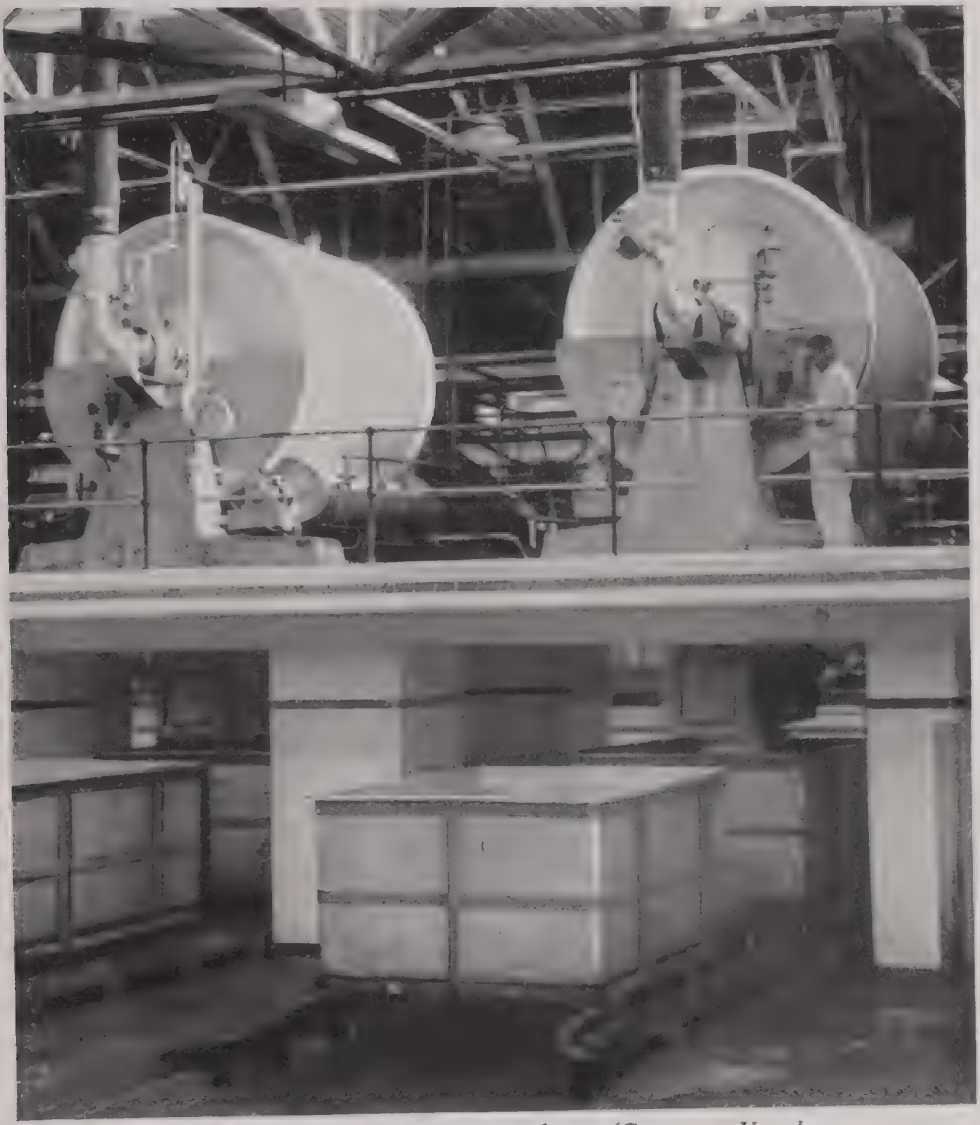


Fig. 54. Installation of cooling drums (Courtesy: *Van den Berghs and Jurgens Ltd.*).

A number of firms now construct cooling drums for direct ammonia expansion. The operating principles are similar, though there are variations in details. A few examples will be mentioned to illustrate these.

The *Silkeborg Engineering Works*, Denmark, make drums of a special quality of Siemens-Martin steel, the capacities vary from 0·25 to 2·5 tons per hour. Fig. 55 is an illustration of the drum aggregate. The feeding trough and the spreader bar above are jacketed for warm water circulation and can be tilted back when not in use. The distance between the drum surface and the bar is regulated by precision screws which are set to give the desired thickness of the emulsion layer. The trough is also adjusted by regulating screws to fit to the surface of the drum which forms one side of it. Trough

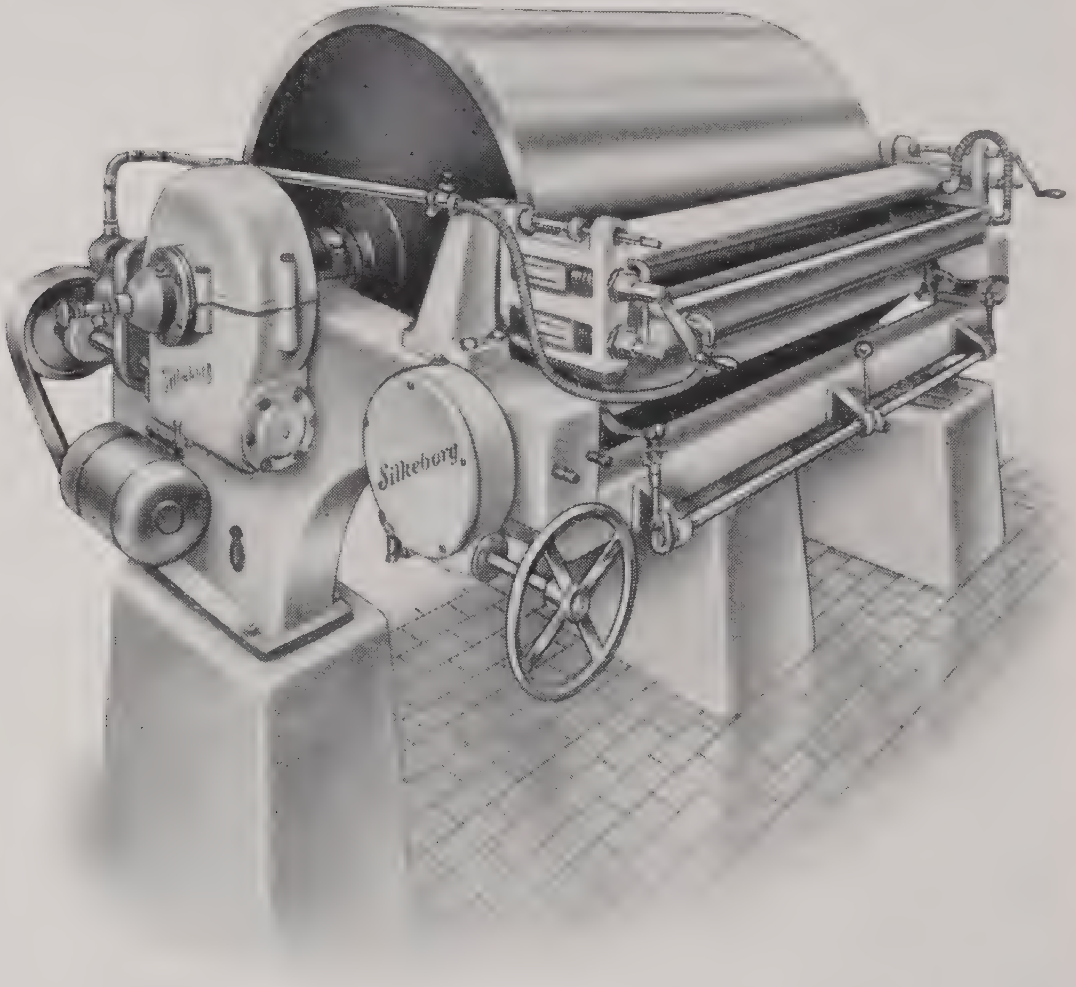


Fig. 55. Silkeborg cooling drum for direct ammonia expansion (Courtesy: *Silkeborg Engineering Works*).

and equalizer bar are made partly of stainless steel, partly of tinned copper alloy. This make of drum is provided with two scrapers, one made of steel to remove the layer of ice forming on the cold surface before the emulsion is applied, the other, the emulsion scraper, made of a special quality of bronze. When the plant is started up and the drum has reached the crystallization temperature the layer of ice is removed by the ice scraper, the feeding trough and bar are placed in position, the emulsion run into the trough and on to the drum, and the emulsion scraper is then set to function. When stopping the cooling, the inlet valve for liquid ammonia is closed, and when the feeding trough is empty it is withdrawn from the drum together with the bar. When there is no more emulsion on the drum surface, the emulsion scraper is put out of operation. Cleaning of the surface should be with cold water and wiping; hot water should be avoided.

A flow diagram for the ammonia system for the Silkeborg drum is shown in Fig. 56. The cooling drum (*1*) has an annular space for the evaporating ammonia which as liquid enters the drum through the central shaft and reaches the annular space through radial pipes at one end and is withdrawn as vapour through similar pipes at the other end. The vapour passes via pipe (*10*) to a float tank (*2*), which is partly filled with liquid ammonia, and via valve (*13*) and pipe (*3*) to the suction side of the compressor. The compressed and liquified ammonia returns from the condensing system via pipe (*4*), valves (*5*) and filter (*6*) to the float tank, in which a float valve operates as regulation valve for the system and passes the ammonia from the compression side to the low-pressure evaporation side. A pump (*7*) draws liquid ammonia from the float tank via pipe (*8*) and passes it through pipe (*9*) and the central shaft of the drum to the annular space of the cylinder, where by the heat of the emulsion some of it evaporates and together with some liquid ammonia is carried by radial pipes at the opposite end to an annular pipe surrounding the inlet pipe for liquid ammonia; through pipe (*10*) this vapour-liquid mixture reaches the float tank, where the liquid is separated from the vapour. that is drawn to the suction side of the compressor. Lubricating oil that may get into the ammonia during circulation will collect at the bottom of float tank (*2*) and can be removed by careful manipulation of valve (*12*). The space between the inner cylinder of the annulus and the central shaft is filled with insulation material.

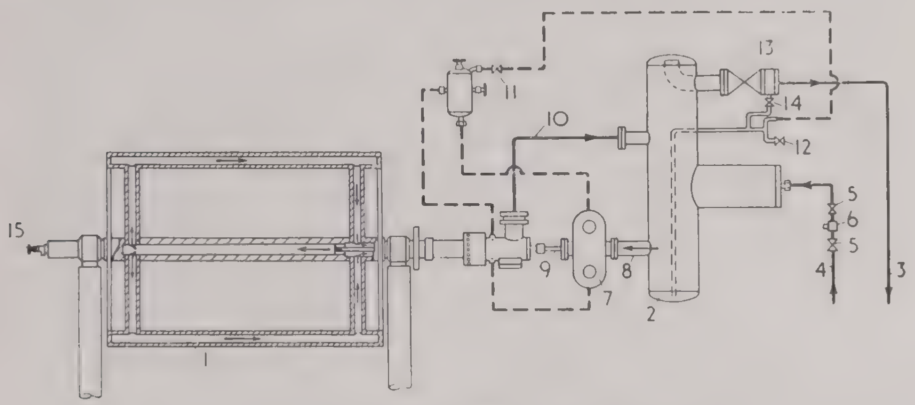


Fig. 56. Ammonia flow sheet for Silkeborg drum.
(Courtesy: *Silkeborg Engineering Works*).

The direct ammonia expansion drum, the Diacooler, of *Gerstenberg and Agger*, Copenhagen, Fig. 57, is used in many factories, particularly as part of that Company's plant for continuous processing (see page 214). It is built in sizes from about 0·25 tons to 3 tons per hour of steel, often coated with stainless steel or hard chromium. The inlet and outlet for ammonia are arranged concentrically at one end of the central axis *A* in accordance with the maker's patent [160] and the temperature at the inside of the cylinder surface is usually about -20°C. The drum is built with an inner and an outer cylindrical wall separated by an annular space; the inner wall is perforated to act as a strainer through which the ammonia passes on its way to the outer cylinder surface. The drum is driven by an electric motor and is geared to rotate at 60–70 r.p.m. The feeding trough *B*, which is placed at approximately the level of the drum axis, is jacketed for warm water *C*, is open at the top end and utilizes the drum surface as one side. An adjustable and heatable bar *D* at the top of the trough regulates the thickness of the emulsion layer on the drum surface, and a float *E* regulates the level of the emulsion in the trough by actuating a valve in the pipe line from the emulsifier. The scraper blade *F* is placed just below the trough and, like this, can be withdrawn from the cylindrical surface by special gear. The scraper blade is made of steel, stainless steel or bronze, according to the hardness of the drum surface, the alloy being arranged to ensure clean removal of the emulsion film without excessive pressure on the drum; this pressure is being applied through springs and screws with handwheel *G*. The high speed of the drum, 60–70 r.p.m., and consequently the short-time exposure to the refrigeration effect, necessitates the use of a very thin film of material on the drum, less than 0·1 mm, which is best achieved by working with a thin emulsion; the temperature of this, when delivered to the feeding trough, depends, of course,

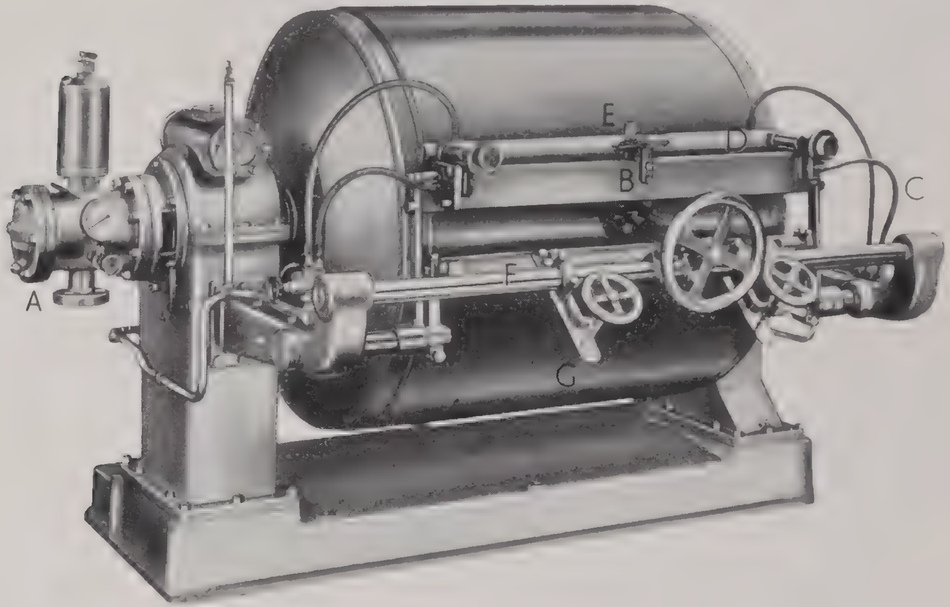


Fig. 57. Gerstenberg type diacooler (Courtesy: *Gerstenberg and Agger, Copenhagen*).

on the composition of the blend. To avoid a tendency of this thin emulsion to show signs of separation in the feeding trough or the buffer tank, if such is used between churning and cooling, it is advantageous to use adequate emulsion stabilizers. Furthermore, with some blends it is a definite aid to ensure the right crystallization during the short exposure to low temperature on the drum and in subsequent working, if the churning or emulsification process is carried out under such conditions of temperature, that microscopical crystallization centres or nuclei are established, before the emulsion is applied to the surface of the drum. The thin emulsion also prevents the incorporation of excessive air and thus improves the heat transfer on the drum, but the short exposure results in the products being only slightly supercooled and the solidified thin film leaves the drum in a coherent sheet; crystallization is therefore soon stabilized in conformity with the temperature, usually in a few minutes, which is of importance in the continuous process.

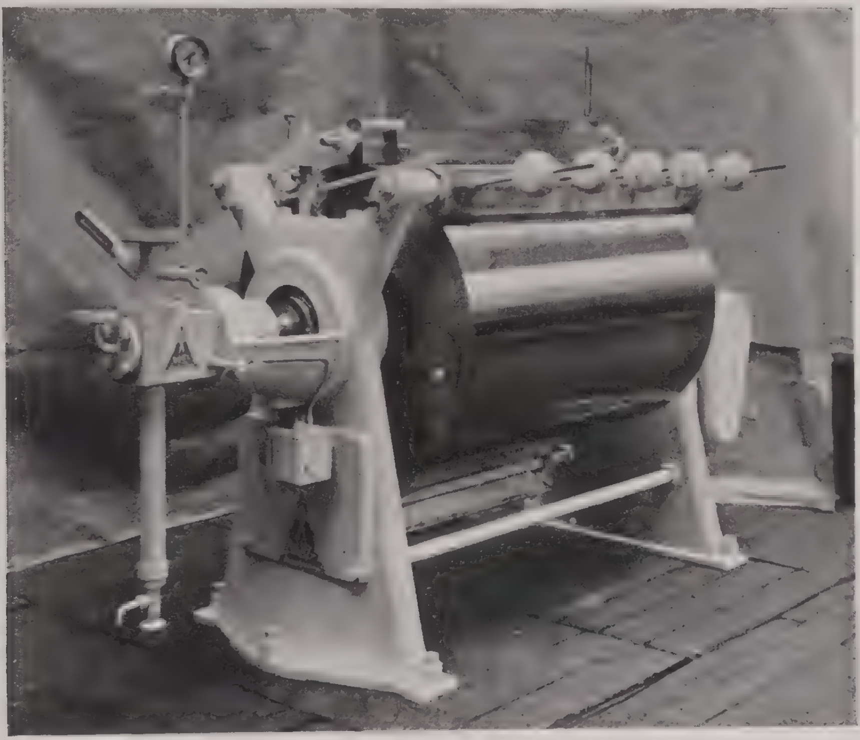


Fig. 58. Atlas cooling drum for direct ammonia expansion (Courtesy: *Atlas A./S., Copenhagen*).

The *Atlas Company*, Copenhagen, who were the makers of the earlier Schou cooling drums working on the double-drum system with brine (see page 173), now build drums for direct expansion of ammonia on the single-drum system. They are made with cooling surface of a special stainless steel, and the liquid ammonia is carried by a closed pipe right into the drum. This plant differs from those already described by having the feeding trough at the highest point of the drum as shown in Fig. 58 which gives a view of this make of drum. The drum surface forms the movable bottom of the stainless steel trough, the vertical wall of which can be warmed by circulating water; its distance from the drum surface can be adjusted to the desired film thickness and no packing strips for tightness are needed. The scraper knife is made of laminated special steel and is placed on a bar resting in special bearings for easy removal from the scraping position. The pressure on the bar and scraper blade is effected by a number of counterweights. The position of the scraper high up on the drum surface in front of the feeding trough necessitates the use of a special funnel or hopper for collecting the solidified film of emulsion and directing it to a conveyor belt, as will be described later in connection with the Atlas Lardin plant for continuous working of which this drum forms an integral part (see page 224).

In some arrangements of cooling drum installations, where difficulties are at times experienced in keeping a steady level of liquid ammonia or film of it on the rotating wall, a fixed feeler pipe to the desired level of liquid can be introduced through the shaft and connected to the suction pipe outside the drum. When the liquid level approaches the open bottom outlet of the feeler pipe, liquid is carried into it, and a contact element of a thermic regulator valve, fitted in the feeler pipe outside the drum, comes into operation and cuts down or off the access of liquid ammonia to the drum. Liquid ammonia carried along in the suction pipe from the feeler pipe is trapped in a separator, where it is evaporated by heat-exchange against liquid ammonia from the pressure side, which is thereby itself cooled down [161].

After the introduction of the dry cooling method on chilled revolving metal surfaces many minor variations of the system were suggested and patented from time to time, most of them dealing with methods for applying the emulsion as an even uniform layer and for ensuring the most economical and efficient heat transmission to the refrigerant, but those described above are the best known and most widely used.

It has also been proposed, and some plants have been in operation, to solidify the emulsion by spraying it through "atomizing" nozzles into a chamber of cold air, from which the solidified globules are continuously removed by screw conveyors [162] [163]. This system would appear to entail considerable risk of air infection and moisture evaporation, as well as being somewhat thermally uneconomical, as air is a poor heat transfer medium. Another spray-cooling method was patented by K. Erslev [164], who suggested dispersing the emulsion in a cold vacuum chamber by means of a rapidly spinning disc; evaporation of part of the moisture assisted the cooling, and the solidified powdery emulsion was removed by a screw conveyor. As far as is known this method did not develop beyond the experimental stage and does not seem of practical value.

The quite recent development of tubular coolers in which solidification of the emulsion takes place while the solidifying product is being plasticized and further emulsified will be dealt with later when these continuous processes are described (see page 228).

It should, finally, be mentioned in connection with the solidification of the emulsion, that in some countries, mostly semi-tropical and tropical, the emulsion is solidified by cooling it down under fairly rapid stirring in the churn to thick viscosity and running it direct into containers, usually tins, in which it rapidly sets in cool storage. By using a suitable fat-blend and, because of the climatic conditions, a fairly high melting-point, 38–42°C, a margarine of smooth texture can be produced but it is of hard consistency and only plastic within a narrow temperature range near the melting point; it is rarely required for spreading on bread. This method is often designated the "Churn-to-Container" method. Milk is seldom used in the aqueous phase and effective emulsion stabilizers are essential.

The Indian type of margarine, the ghee substitute Vanaspati, a 100 per cent vegetable fat product, is also frequently cooled by tapping it from a temperature-regulating vessel, a mixing tank or churn, direct into metal containers, but with this product crystallization conditions are in most cases so adjusted that a grainy substance is deliberately obtained in imitation of the natural ghee. It is a semi-fluid grainy mass at higher room temperatures, but sets again as a grainy plastic fat on cooling. For further details of manufacture of Vanaspati, see page 261.

Post-Cooling Treatment : Tempering

As the result of the shock-cooling process the solidified margarine in its granular or flaky crystalline form is, even after stabilization when supercooling has been discharged, at a temperature well below that at which it will ultimately be used; the ratio of solid to liquid glycerides is excessive and the product lacks plasticity. The temperature a few minutes after the margarine leaves the cooling plant is, according to the method of cooling, 4°–7°C and rises then slowly while crystallization approaches completion. In most of the fat mixtures used for margarine the crystals are formed in the stable form and the difficulties with polymorphism, experienced with rapid cooling of cocoa butter or shea butter, are rarely found. Many manufacturers prefer, however, to give the margarine a resting or maturing period after cooling, while allowing it to increase in temperature to, preferably, 12–15°C, partly to ensure a more suitable solid-liquid glyceride ratio for kneading and plasticizing, partly to promote in margarine churned with ripened milk a more thorough absorption of the flavouring principles by the fatty phase. The latter step, which gave rise to the term "maturing," was at one time considered important, probably because the ripening of the milk was often curtailed at a stage, when the aroma forming bacteria had not had time to complete their particular function before the milk was cooled. The aeration and warming up in the churn and the maturing period of the granular or flaky product provided then an opportunity for an after-ripening of the milk phase and absorption in the fat of the aroma compounds, which were formed, unless the margarine was fully salted in the churn. The modern ripening technique and the extensive use of chemically produced butter aroma compounds make this maturing period less essential and often superfluous. Many manufacturers extend never-the-less the resting period to 12–18 hours for better glyceride balance, particularly with pastry margarines.

In some continuous processes the rest period is limited to a few minutes, in some it is omitted entirely, but in these processes steps are taken to increase the temperature to 10–15°C before the principal kneading and plasticizing is done.

To get the best result from mechanical working and kneading of the margarine, it should preferably be at such a temperature that the ratio of solid to liquid glycerides is about 35–40 : 65–60, which in most cases means a temperature of 10–15°C. Modification in composition because of climatic conditions may necessitate adjustment of temperatures. The mechanical working is designed to give the margarine the desirable and important characteristic property of a suitably firm and smooth consistency, form-retaining under its own weight and pliable, not hard and brittle; when subjected to pressure or stress it should be plastic enough to yield in shape without showing crumbly fracture. This property is important not only for its spreadability when used as table margarine, but also for its value as a shortening when used in flour confectionery.

The preferred firmness of the consistency varies from place to place according to consumers' preference; some want a firm "body" of the margarine, some a softer and more pliable product. As the firmness is related to the solid : liquid glyceride ratio and this varies with the temperature, and therefore with the seasons, the manufacturer adjusts as far as possible his fat-blend to meet seasonal variations, so that his product has the most suitable glyceride ratio at the conventional temperature of usage. Mechanical working is, whatever the composition, the best method of giving the shock-cooled margarine the cohesive, uniform, pliable "body" which is required, and if the kneading is done at an appropriate temperature, according to the fat-blend composition, i.e., the glyceride ratio, the pasticity is less affected by subsequent temperature variations, although the firmness may vary to some extent.

The solidified fat consists, as mentioned in earlier chapters, of a skeleton or network of crystals of the solid glycerides which by adhesive forces hold together the semi-liquid and liquid glycerides. Kneading breaks down the rigidity of the network and rearranges it in such a way that the crystals by re-orientation acquire greater mobility in the liquid portion; rigidity changes to plasticity. This change takes place more easily and with less consumption of power, if there is a suitable crystal size distribution and at a temperature that gives a solid glyceride proportion of 35–40 per cent. If the temperature is too low, the proportion of liquid glycerides and their relatively high viscosity at that temperature lessens the free movement of rearrangement of the crystals, and although mechanical compressing or shearing power and the frictional heat in the kneading plant can cause some cohesion of the mass, it soon reverts to a crumbly structure. Where kneading takes place in relatively thin layers on rolling plant, kneading tables and similar devices at workroom temperatures, there is often by friction and heat transfer from the air an increase in temperature to one more suitable for the process, but such kneading treatment has often to be repeated to get a suitable plasticity in the product. At a higher temperature and lower solid glyceride proportion the yield point is reached at lower stress, and this is more uniformly distributed with the result, that plastic flow without disruption takes place more widely through the mass. The best result of the kneading operation is therefore obtained, if the yield point is reached without crumbly disruption of the product.

These features can be expressed graphically in the Bingham Curves (Fig. 59) in which stress is plotted against rate of flow. Curves *A* and *B* are those of true liquids where flow begins immediatly stress is applied and continues at a rate proportional to the stress; the slope of the curve depends on the viscosity; *B* is more viscous than *A* and its rate of flow less than that of *A* at same stress. *C* represents the curve for a plastic solid such as margarine, where flow does not begin, until by application of a certain stress *X* the yield point is reached and deformation begins. Because "slip" occurs in plastic flow of margarine, the curve *C* is not a straight line to begin with; the ideal plastic flow is, according to Bingham, represented by line *D*. A firmer margarine has a higher yield-point, i.e., it requires a greater stress to initiate deformation, as for example *Y* for curve *E*. When the effect of "slip" ceases, the curves become straight lines and the rate of flow proportional to the stress. The slope of the straight line reflects the viscosity which, like the yield point, is related partly to crystal size, partly to solid-liquid glyceride ratio, and therefore dependent on temperature; but in considering the plasticity of margarine the influence of the closeness of the emulsion must be borne in mind, although this affects more the appearance and the palate sensation than the spreadability.

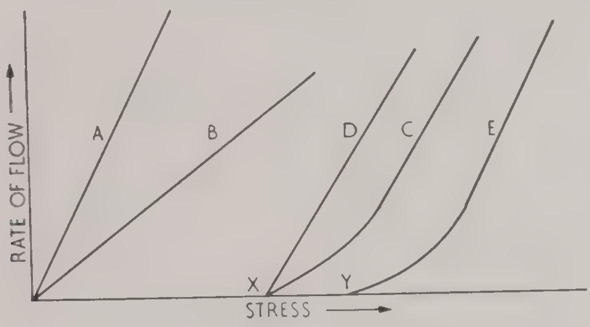


Fig. 59. Bingham curves for flow.

Shortenings, which consist entirely of fats or mixtures of fats and oils, and which are used for making the batter or dough in flour confectionery, have often a glyceride composition of the same type as margarine fat-blends;

they are solidified and crystallized by processes similar to those used for margarine, except the wet process. Their consistency and plasticity are as important as those of margarine and are "stabilized" and made less temperature-dependent by tempering of the solidified product at rather high temperatures, 25–30°C, for a prolonged period, such as 24–48 hours, after being filled into containers or packages. After the period of tempering, which causes a rearrangement of the crystals and their sizes by partial melting of the lower-melting glycerides and slow re-crystallization with formation of an adequate mixture of larger and smaller crystals during subsequent cooling in storage, the fat is conditioned to regain its most desirable plastic properties at the temperature of usage, even if exposed to intermediate periods of changing temperatures of a reasonable order, as it is then the sizes, but not the number of crystals, which increase.

Such tempering is not practical or possible with margarine, partly because it would often unbalance the emulsion by causing coalescence of water droplets in the softened matrix of the fat-structure, partly because it might cause evaporation of surface moisture, part-release of occluded air, loss of volatile aroma substances and, in milk margarine, cause potential bacterial degradation processes.

Fat is a poor conductor of heat. Although in most cases margarine is solidified in thin films, there can be a variation of 2–3°C in the flaky sheets falling from the drums and in the loose material in the collecting receptacles, while supercooling is released and during the following slight increase in temperature. Working and kneading helps to equalize the temperature as well as to break down the crystalline rigidity, and the effect is the greater when the temperature is 10–15°C, corresponding to 35–40 per cent solid glycerides, which temperature generally gives the best viscosity of the liquid glyceride fraction. The optimal temperature depends on the composition of the fat-blend, and margarines containing high proportions, 60–70 per cent, of such fats as coconut and palmkernel oils are preferably worked at somewhat higher temperatures, 15–17°C.

Though mechanical working at higher temperatures requires less power and time, care must be taken that the margarine is not too soft, as it may then get "overworked" and greasy before the product is homogeneous; material in direct contact with the kneading surfaces may become too soft and adhere and cause internal rupture in the mass, some of which, through less impact of the kneading forces, form firmer lumps in softer parts. There is also the possibility of the phenomenon of thixotropy showing itself; this causes a reduction in viscosity and thus excessive softening of the consistency of the mass, and it may take some time before the right consistency is re-gained. With some compositions there is a slow reversion to a more rigid crystalline texture with some loss of plasticity.

The correct temperature for mechanical working and the amount of working are therefore inter-dependent and a matter of experience and of knowledge about the fat-blend. Several methods have been adopted for attaining the best, or at any rate a suitable, temperature before kneading the margarine.

The simplest is to leave the solidified margarine at rest at work-room temperatures for a prolonged period, 12–14 hours. Owing to the low heat transfer in the mass it takes many hours, before a good kneading temperature is reached. Some manufacturers provide tempered air-conditioned rooms for this resting period, but the temperature can only be held a few degrees above that aimed at for the margarine without excessively softening surface layers in the storage containers, and even if these layers reach the temperature it is not in practice possible to wait for the whole bulk to get the same temperature; the equalization of temperature must therefore be effected by kneading. Long storage at kneading temperature also entails the risk of infection from air and undesirable growth of micro-organisms.

In the continuous processes, where kneading follows practically immediately after cooling, arrangements are usually provided for tempering the product, while being compressed before and during kneading, but only small temperature differences between heating surfaces and margarine can be employed without risk of spots or streakiness in the compressed margarine. It is, however, highly desirable that the crystallization of the emulsion is practically finished, before warming up begins, as otherwise instability in the crystal structure may lead to graininess in the margarine; hence, in the continuous processes, the solidification of the emulsion in a very thin film is very important. In those continuous processes, where cooling and plasticizing takes place at the same time, it is essential, that correct crystal-nucleus formation in the fatty phase takes place, before the whole emulsion is cooled down to solidification temperature, and after solidification careful tempering and temperature equalization with or without moderate stirring of the soft thixotropic product is important to ensure that it sets finally with the desired consistency.

To shorten the resting period and regulate the warming up of the solidified product from the discontinuous process, some manufacturers transport it in thin layers on belts through tunnels in which the air is heated to an appropriate temperature, which must be well below the melting point of the margarine. Ehlers [165] described such a process, and many similar arrangements have been in use in various places. The intention has usually been to deliver the margarine with a suitable temperature and workability direct into the kneading machinery, but in some cases the principal object has been to warm it up to a temperature more appropriate to after-ripening and maturing. Owing to the poor heat conductivity of the loose flaky product and the low temperature gradient and heat transfer between air and margarine the method is of doubtful efficiency, and the tempered product is rarely of uniform temperature until mixed and worked in the kneading machinery. The large volume of air and its rather high linear speed tend to cause evaporation of moisture from the flakes and sometimes blow fragments off the belt. If the latter is of organic material, canvas, rubber or mixtures of these, there is the further risk of growth of moulds and other harmful micro-organisms on the belt and in inaccessible places. This risk is considerably reduced when metal belts and equipment is used, as this can be sterilized from time to time, but unless stainless steel or other non-corrosive and non-catalytic metal is used, there is a risk of corrosion and rust from attack by salt and acid components of the margarine.

It has also been proposed to temper the margarine after cooling by transporting the loose mass in thin layers on a metal belt, which is warmed on the underside by sheets or jets of water of suitable temperature, but the heat transfer to the loose mass is low and irregular, and as a wet tempering arrangement this system has mostly been abandoned. Its use after consolidation of the cooled margarine to a flat cohesive ribbon, which is spread on the belt, has been proposed by Unilever Ltd. in connection with continuous processing and solidification in tubular coolers [166].

A very effective method of tempering the margarine flakes, though rather costly in labour, was widely used in earlier years and is still in use in some factories. The cold crumbly margarine was, after removing a cover plate on one end, filled into a horizontal rotatable cylinder, usually made of hardwood, but in some factories of aluminium or stainless steel. After replacing the cover plate an approximately equal quantity of water of 20–22°C was run into the vessel during slow rotation, until it was half full. The actual temperature of the water varied slightly with the composition of the fat-blend. The cylinder was then rotated at 80–100 r.p.m. and the contents thoroughly stirred and mixed for which purpose the cylinder had longitudinal shelves or bars along the wall, fixed in radial direction and of a width about 10 per cent of the diameter. Heat was in this manner transferred uniformly to the margarine, which thereby softened, became more plastic and conglomerated into coarse granules. The water was next drained off and the pliable margarine granules were worked together to form large plastic masses by being carried on the shelves during slow rotation to the top of the inside of the cylinder and falling to the bottom, or by pushing into the cylinder through the removable end a carriage with two fluted rollers, driven from the gear box for the cylinder (see Fig. 60); by passing repeatedly between the rollers the material was kneaded together in plastic masses and excessive water could be worked out. These treatments gave a tempered and plastic product which required little further kneading.

If the margarine had been churned with the theoretical amount of milk for the desired final composition, tempering with water would cause excessive loss of water-soluble constituents and tempering was then done by means of a mist of steam blown in through a spray nozzle, while the vessel rotated at full speed. The latent heat of the instantaneously condensed steam mist was sufficient to cause the required rise of temperature uniformly throughout the granules in a few minutes, with negligible increase in the moisture content of the margarine. The tempered product was then consolidated into bulky lumps by falling from top to bottom, and the finished material could be removed either through an opening in the cylindrical shell or on a tray on the roller carriage. Rolling was rarely needed in the dry steam process. The steam should be odourless and preferably from de-aerated water; when water is used as tempering medium it should be of drinkable quality and bacteriologically pure, preferably sterilized.

Although it is desirable, also in discontinuous processes to do the mechanical working and kneading at appropriate controlled temperatures, the disadvantages of long storing periods in air-conditioned rooms or of elaborate tempering machinery are such, that most manufacturers rely simply on the gradual temperature increase while the margarine is kept in the process rooms or is transported in shallow layers on belts from cooling to kneading plant, and while it is being worked on kneading plant of various constructions, where it is repeatedly spread out and exposed to room temperature. Several kneading treatments are often given and by mechanical force and gradual increase in temperature, and consequently modification of the solid-liquid

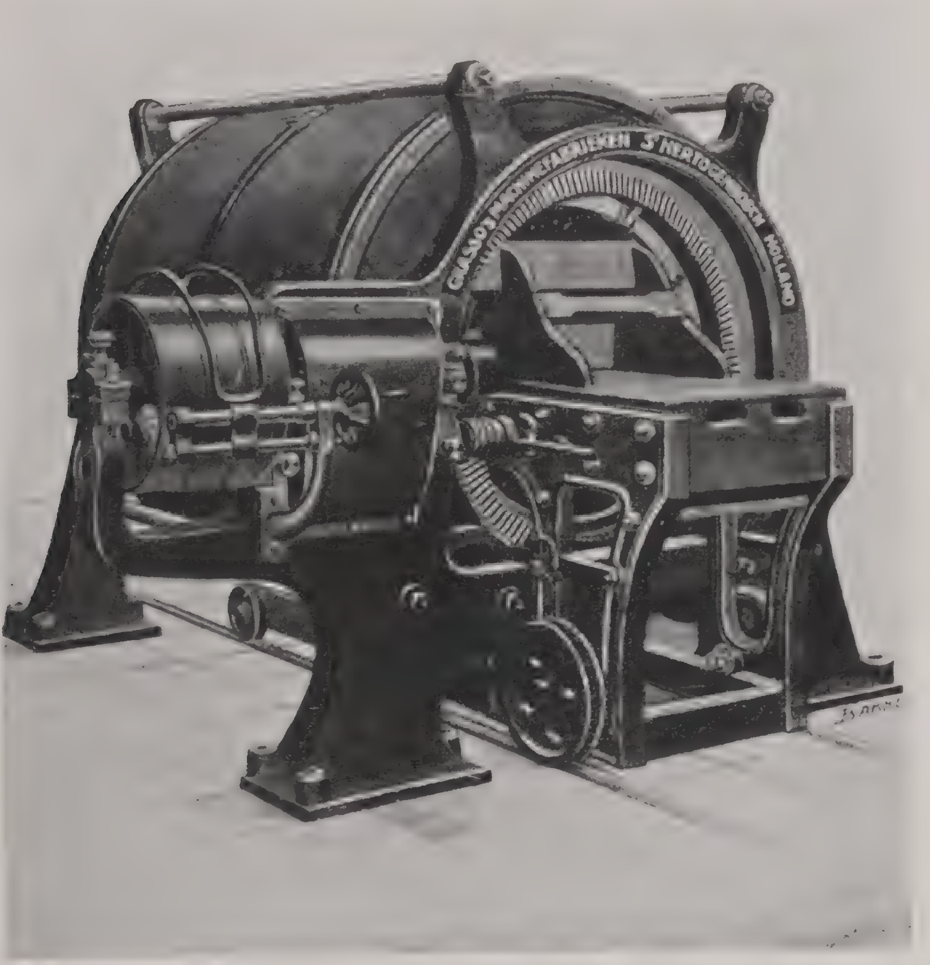


Fig. 60. Tempering and kneading vessel.

glyceride ratio, the desired plasticity and "body" in the margarine is attained. More difficulty is caused by too high temperatures in the process rooms during warm seasons or in hot climates, as the margarine may get too soft to tolerate sufficient working to make the consistency and texture homogeneous. In such cases it is necessary to work in temperature-controlled rooms or to rest the margarine in cooler rooms between the various processing steps.

Kneading and Rolling of Margarine

This is done by submitting the margarine to deformation by pressure and shear on plants of various constructions. If the solidified emulsion contains excess moisture, the pressure and intensiveness of the kneading process is regulated so that excess is pressed out, preferably while the margarine is still rather hard and the yield point so high that the effect is more one of pressure than of shear. Kneading at too low yield point may cause an emulsification effect with retention and further dispersion of the moisture into the fatty phase. In modern manufacture the margarine from the cooling plant rarely contains excess moisture, and the effect is principally one of shear, partly because of slight adhesion of the contact layer of margarine to the plant surface in the absence of the lubricating action of expressed moisture, partly because of slip between internal strata of the margarine as the result of differences in viscosity and, sometimes, thin films of occluded air from bulking of the original loose granules, and partly because of differential surface speed of the kneading surfaces. The best permanent results are obtained, when deformation and kneading involves only a moderate amount of shear; excessive shear may lead to thixotropic effect with its potential damage to the permanent pliability of the margarine.

Owing to the thorough mixing and blending that kneading causes, salt and other ingredients are often added at this stage.

Although many types of kneading plant have been and are used, the principal ones fall in three groups:

Rollers
Horizontal kneading tables
Closed mixers or blenders.

Rollers.—These are pairs of parallel cylinders, rotating in opposite directions, made of hardwood, steel clad with stainless steel, porcelain or stone of the close-grained granite or porphyry type. Rollers have from one to four or five pairs of cylinders; the distance between the cylinders of a pair is adjustable in accordance with the rolling pressure required. Smooth-surfaced rollers frequently rotate at differential speed to increase the shearing effect, the ratio of rotation speed varying from 60 : 80 r.p.m. to 55 : 110 r.p.m. Some wooden rollers have a grooved or fluted surface, the ridges running parallel or at a slight angle to the axis; this arrangement helps to draw in better the margarine, when the distance between the rollers is small, and to express surplus moisture. A similar design of surface for metal or stone rollers has not been successful because of the greater adhesion of margarine to these materials, which necessitates the use of scrapers for removing adhering margarine. Sometimes metal rollers, and at times also those made of porcelain, are built for internal circulation of temperature controlled water to enable the temperature of the margarine, and thus the plasticity, to be adjusted to the mechanical effect.

In smaller factories the loose margarine granules are shovelled on to the rollers through a feeding hopper or to a conveyor, that lifts the material to the hopper. In large factories mechanical lifting gear is used for tipping the contents of trucks or containers into the feeding hopper. Trucks are often made with hinged ends. The lay-out of some factories is such, that the material is dumped through openings in the floor into feeding hoppers below. Supply from hoppers to rollers must be gradual to avoid overloading and "bridging" on rollers. Where output and lay-out justify it, some factories ensure such regular flow to the rollers by means of belt conveyors direct from the cooling plant, sometimes combined with a tempering stage, as already mentioned.

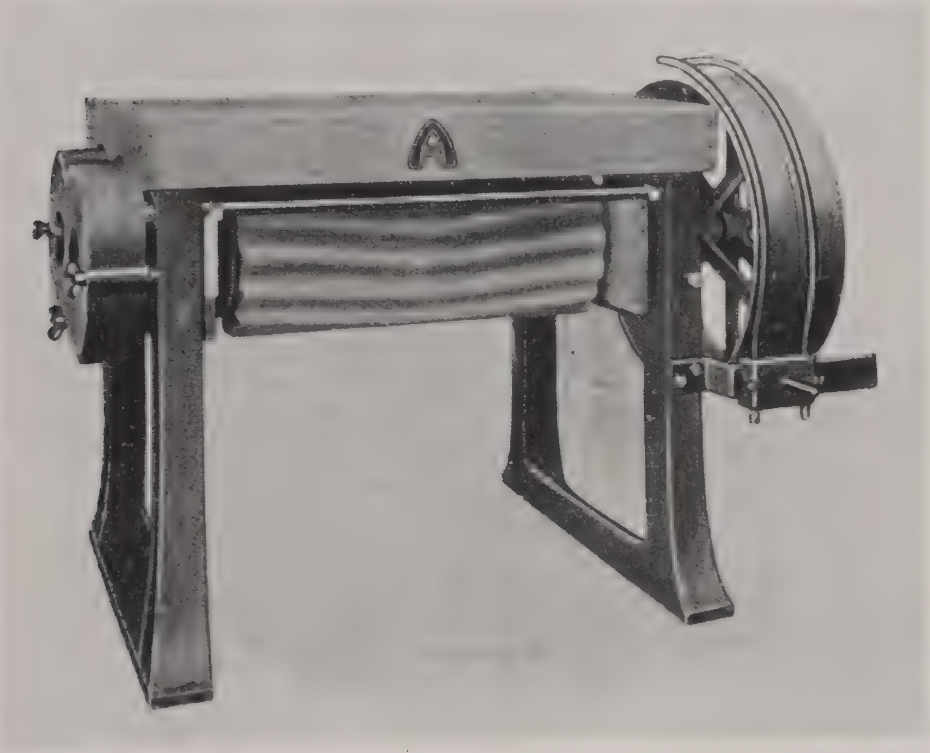


Fig. 61. Single roller pair, grooved.

The simplest arrangement is the single pair of rollers. Fig. 61 illustrates a machine with grooved rollers made of beech or mahogany, 3–4 ft. long and

1 ft. 3 in. to 1 ft. 6 in. in diameter. This construction requires that they revolve at the same speed, driven by gear wheels outside the machine. The feeding hopper slopes towards the middle so that the material is delivered into the space between the rollers. It is usually passed through the machine several times, with a short rest between each passage. A shallow wagon under the machine collects the treated material.

Fig. 62 shows a single-pair roller machine, but in this case the cylinders are smooth and made of beech or granite; scrapers held lightly against the roller surface by means of counterweights prevent adhering margarine from being carried round and direct it into a truck underneath. Single roller-pair machines are mostly used in small factories; the smooth roller type, as shown in Fig. 62, when made with granite or porcelain rollers, is frequently used for smoothing out unevenness in consistency after earlier kneading processes, due perhaps to rest periods at lower room temperature than that of the bulk of the margarine. Sometimes hollow metal rollers, clad with porcelain, are arranged for cold water circulation for cooling down margarine that has become too warm and soft for further handling, for example in automatic moulding and wrapping machines.

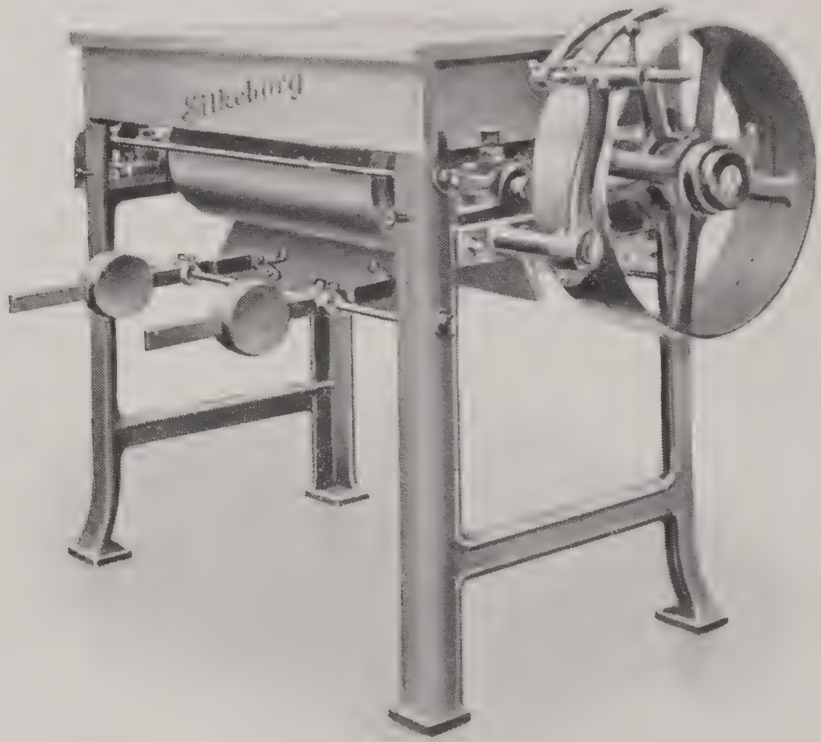


Fig. 62. Single roller pair, smooth (Courtesy: *Silkeborg Engineering Works*).

Fig. 63 is a diagram of an arrangement, by which the material after passing between porphyry smooth cylinders as sheets of adjustable thickness falls into a trough and is mixed and worked by a wooden conveyor screw, that gradually lifts it to a higher level through a wooden tube with a conical mouthpiece, where it is compressed into a solid block before being discharged to a conveyor or a truck. The porphyry rollers (*A*), the distance between which can be varied, are provided with scrapers (*L*), pressed lightly by springs against the rollers and directing the milled material into the trough (*M*) below. It is here thoroughly intermixed, kneaded and conveyed by the worm (*R*) through an extrusion tube with inspection cover (*Q*) and the conical compression mouthpiece (*O*), where it is consolidated into a continuous bar. A cutter arrangement (*P*) at the outlet subdivides the bar into pieces of suitable length. The compression squeezes out excess moisture that drains away down the slope. The conical mouthpiece is hinged on to the extrusion tube and can be swung open. The trough with conveyor and extrusion arrangement is mounted in a movable frame (*N*) on wheels and driven by separate motor, so that it can be removed from the rollers.

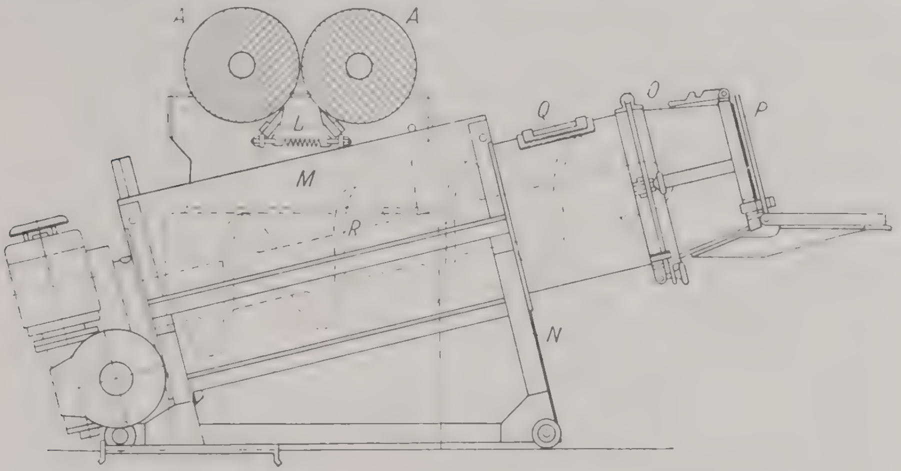


Fig. 63. Single roller pair, smooth, with conveyor and extruder.

As one passage between rollers is rarely enough to give the required mechanical working, particularly of water-cooled margarine, where excess moisture must be removed, machinery is built with two or more pairs of cylinders, the material being conveyed between each pair by means other than manual labour. Fig. 64 illustrates a duplex roller with superimposed roller pairs. In this type the upper pair are wooden grooved rollers, the lower pair smooth rollers, either wooden or porcelain; in the latter case internal water circulation is sometimes arranged. Machines are also built in which both pairs of rollers are smooth, wooden or of other material.

The duplex rollers with superimposed roller pair are not so suitable when margarine is churned with excess moisture, as the expressed water from the upper pair is difficult to prevent from falling into the lower pair. Charging and discharging also require special arrangements. A more popular type of duplex rollers is then that shown in Fig. 65. The margarine is shovelled or conveyed into the hopper *A* and falls between the first roller pair *B*, which is of the grooved wooden type, and down on a belt conveyor *C* that carries it up to a height, wherefrom it falls into the trough between the second pair of rollers, *D*, of smooth surface, wood or other material. As the margarine after passing the first roller pair is somewhat consolidated a hopper is not necessary at the second roller pair. After passing this, which may be provided with scrapers, the material falls into trough *E* with worm conveyor, as shown in Fig. 63, extrusion tube *F* and conical mouthpiece *G*. Excess moisture squeezed out between rollers *B* drains away from the bottom of the belt conveyor. The aggregate is driven by motor *H* and reduction gear *I* at the first roller pair; the second pair is driven from the first by shaft and bevel gears *K*.

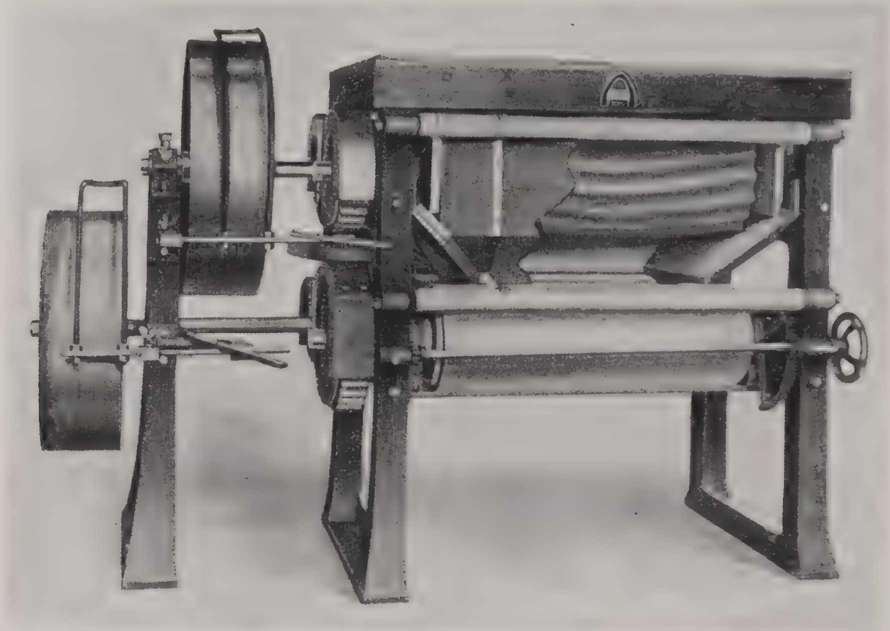


Fig. 64. Duplex roller, vertical.

Machines with more than two pairs of rollers are usually called multiplex rollers and can vary considerably in detail construction, though similar in principle. Plants with up to five pairs of rollers are used, though the most common are those with three pairs, which give an adequate treatment to most qualities of margarine. Multiplexes equipped with wooden grooved rollers give a rather more severe treatment to the margarine, particularly when this is made by the dry cooling process without excess moisture. If it is made by wet cooling or with excess moisture, the wooden grooved rollers are very effective, and the expressed moisture helps to prevent adhesion to the rollers which by revolving at the same speed operate with minimal shear. It is, however, not advisable to use more than three pairs of these rollers in order to avoid overworking.

Modern plants working on dry-cooled material have mostly smooth rollers of stone or stainless steel, with differential speed and adjustable passage slit. Belt conveyors of canvas or, preferably, natural rubber composition are mostly used for transporting the material between the roller pairs; some synthetic rubbers impart a chemical flavour to the margarine. In older types of plant with wooden rollers wooden screw conveyors in open wooden troughs are used for transportation; they have the advantage that a certain amount of mixing and working takes place and cause the material to be pressed in different directions, thereby helping in temperature equalization and plasticizing. There is, however, particularly in warm weather, the risk of overworking. The margarine is usually discharged from the plant through a worm conveyor with extrusion tube and compression mouthpiece, which on plants with stone rollers and belt conveyors are normally made of stainless steel to avoid the risk of infection, often incurred with wooden plant, which is less easy to keep bacteriologically clean. There are, however, many manufacturers

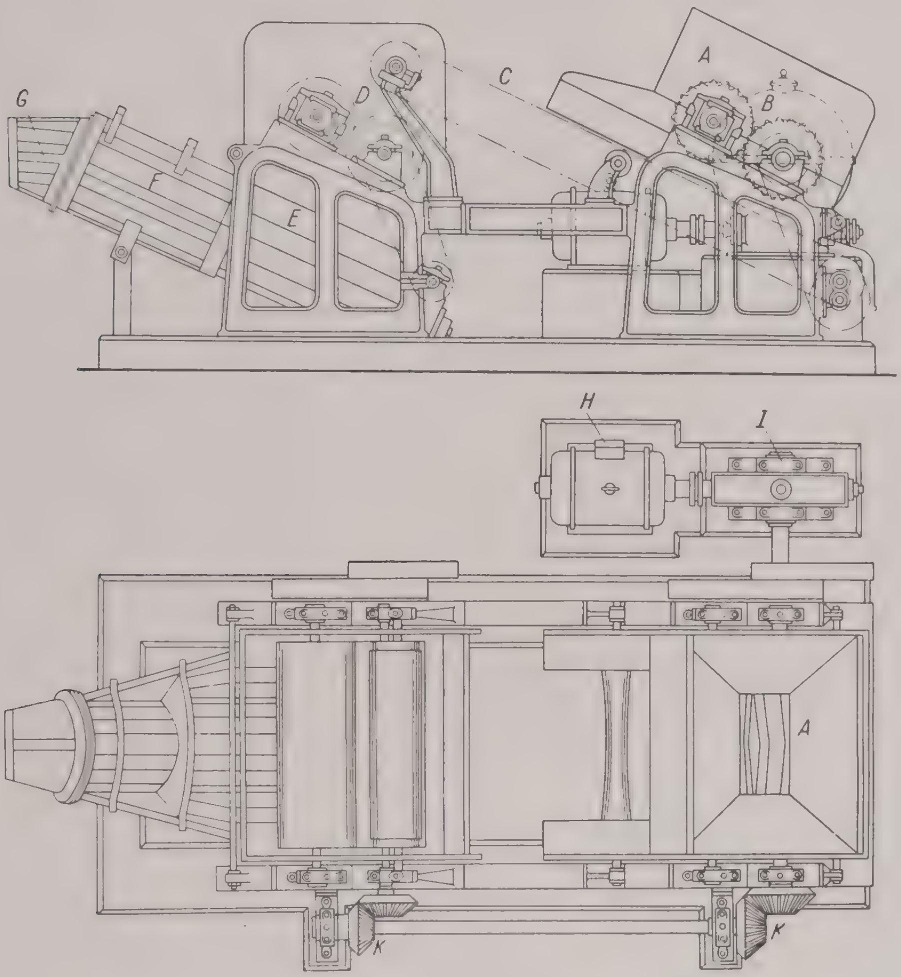


Fig. 65. Duplex roller, horizontal.

who consider wood more suitable than metal for contact with margarine, in spite of the risk of infection.

It is clear that margarine by passing through a multiplex roller in comparatively thin sheets or pieces gets warmed up some degrees by friction and exposure to work-room temperature, and this together with the mechanical kneading effect makes the product of plastic consistency, but it is rarely sufficiently homogeneous for packing as a finished margarine.

In many factories salt is sprinkled on the margarine by hand or by mechanical devices while passing in shallow layers through the rolling plant, and the rolled product is usually analysed for its water content to ensure that this does not exceed the statutory limit.

Fig. 66 illustrates a multiplex machine with four pairs of wooden grooved rollers revolving at 40–50 r.p.m. and driven by bevel gears off a common shaft. The loose margarine is shovelled or otherwise conveyed into the funnel over the first pair and after passing between the rollers is transported to the following pairs by wooden screw conveyors operating in semi-circular troughs. After passing the last pair the screw conveyor presses the kneaded material through an extrusion tube and conical compression orifice piece as already described.

Multiplexes are only used in large scale manufacture as their output is of the order of 10–20 tons per hour; they require 10–20 h.p. for driving, according to the setting of the rollers and the firmness of the margarine.

Where the processing of the margarine is on several floors and the lay-out of the processing line is suitable for it, stage multiplex rollers are sometimes used. Fig. 67 illustrates such a plant, where the feeding hopper is on the floor above, and the product descends by stages through three pairs of grooved wooden rollers, running at 40–50 r.p.m., with initial, intermediate and final transportation by wooden screw conveyors, finally emerging through a compression mouth piece. The conveyors work in open troughs which slope slightly backwards to enable any expressed moisture to drain away.

Fig. 68 is a photograph of a multiplex roller installation in a large factory. These machines have three pairs of smooth porphyry rollers revolving at differential speed to increase the shearing effect, and each pair is driven by an independent motor. The rollers are 3 ft. 6 in. long by 1 ft. 9 in. diameter. The loose margarine from truck boxes, shown in the background, is emptied by a lifting and tipping device into the elevated aluminium silos in the background and from there extruded without compression by a double screw conveyor into the metal feeding funnel for the first roller pair. After passing through this the margarine falls on to a rubber composition belt, which ascends at a suitable gradient to lift the product to the next pair of rollers, where the belt turns over to discharge. A scraper board is held lightly against the belt to remove adhering margarine, and scrapers are also provided for the rollers. After passing the last pair of rollers the product falls into a hopper to be removed by a metal worm conveyor through a tube with compression mouthpiece. On issuing as a bar through the orifice it is sliced into flat pieces

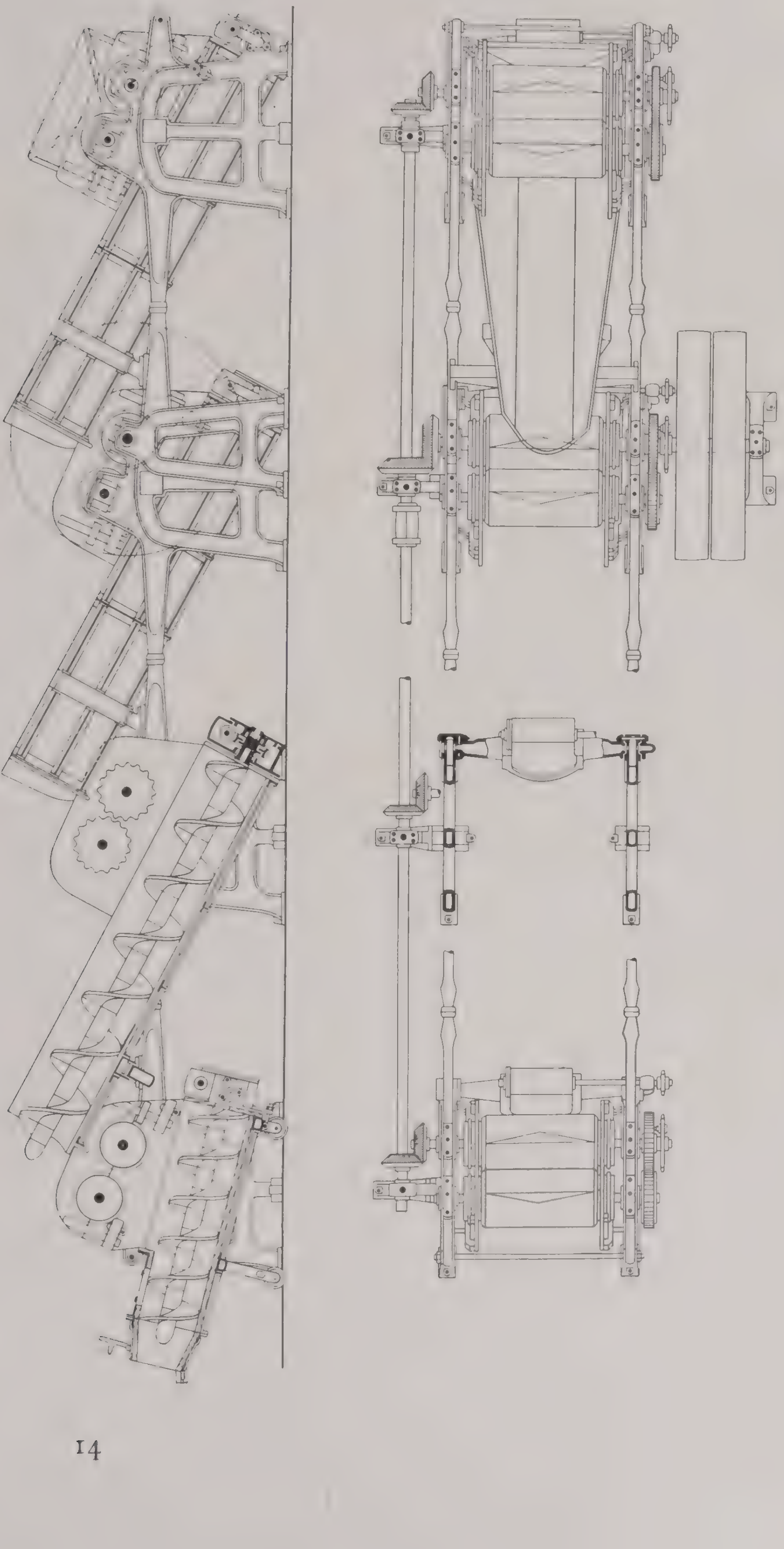


Fig. 66. Multiplex roller with wooden rollers as made by *Harburger Eisen- & Bronzewerke A.G.*

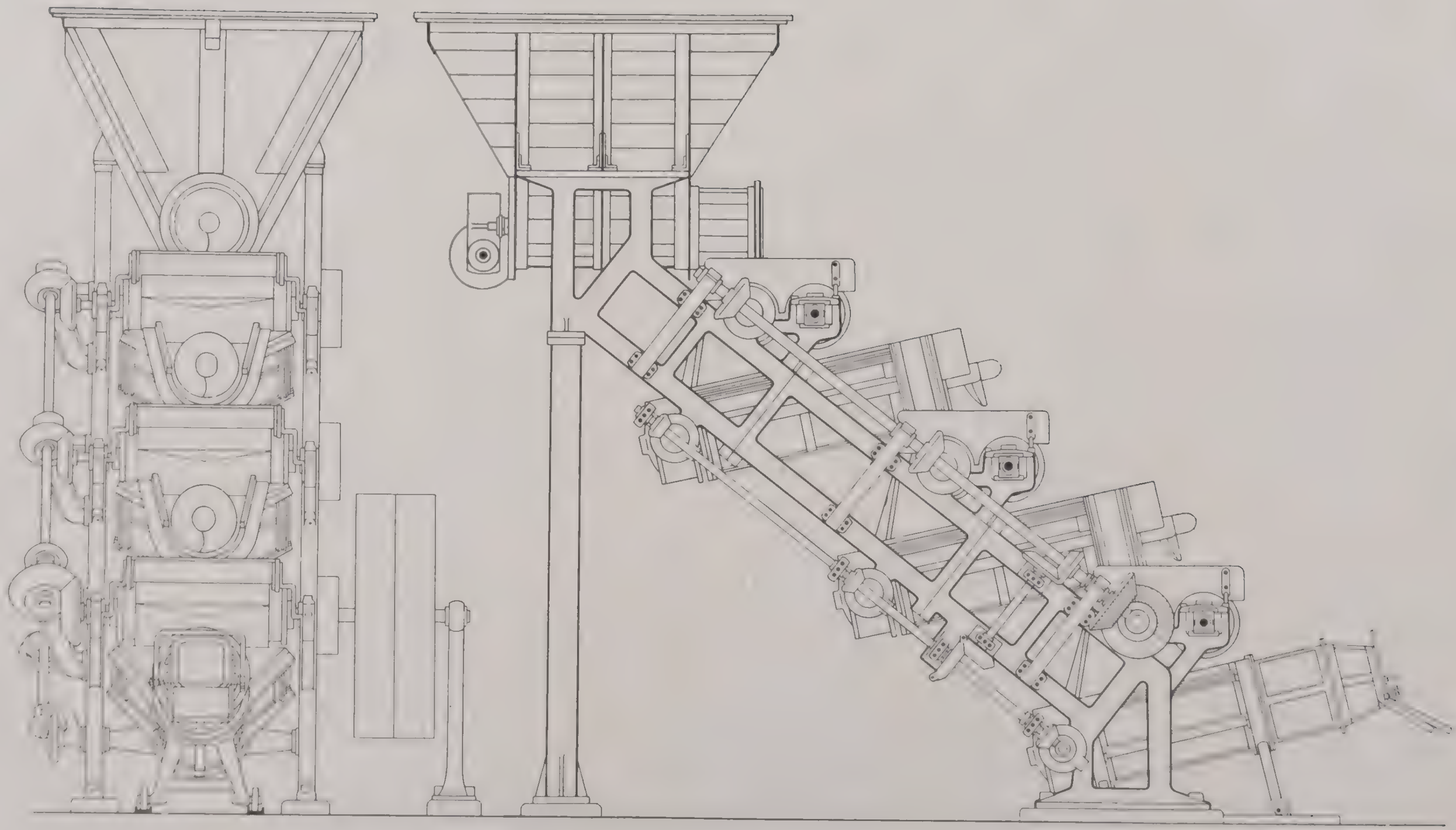


Fig. 67. Stage Multiplex roller, as made by *Harburger Eisen- & Bronzewerke A.G.*

by a mechanically operated cutter and falls on to a belt to be removed to the next process step. This machine is very hygienic and easy to keep bacteriologically clean, as the margarine is nowhere in contact with wood. The output from a machine of this type is 12–15 tons per hour and the total driving power required is about 18 h.p.

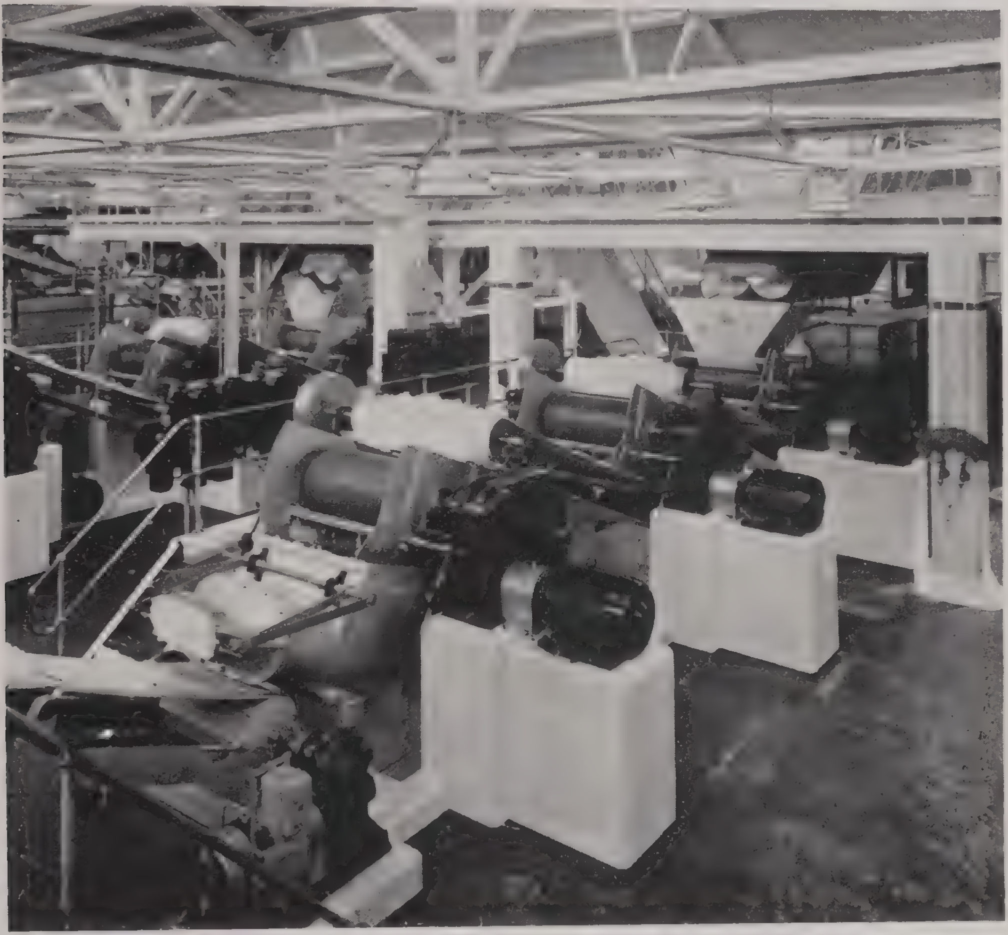


Fig. 68. Multiplex roller installation (Courtesy: "*Food*" and *Van den Berghs and Jurgens Ltd.*).

A combined tempering and rolling machine has been described on page 193, Fig. 60.

The rolling and mixing effect on kneading machines of the roller type, though greatly improving the plasticity, is rarely sufficient to give the homogeneity required before the margarine is considered finished for packing, and in practically all factories a final blending or high-speed mixing is given, as will be described later.

Kneading Tables.—These are horizontal or slightly conical circular revolving tables, on which the margarine is placed in a shallow layer of 2–6 in. thickness and kneaded by being squeezed and rolled between the table surface and kneading rollers of different constructions placed thereon and revolving at the same or slightly higher surface speed than the table. While the product from the rolling machines, though plasticized, may lack uniformity, because limited and small quantities of a batch is kneaded at the same time, and equal treatment during a passage between a pair of rollers is difficult to ensure, a charge on a kneading table, 0·25–1 ton according to the size of the table, is treated, kneaded and mixed until it is uniform in appearance, consistency and composition. These machines can therefore be used to consolidate, knead and homogenize the product from the loose flaky or granular condition from the cooling plant and make it suitable for packing, or they can be used as a secondary equalizing treatment after rolling, or as a conditioning treatment before high-speed blending. The kneading tables are also suitable for incorporation of salt and some other ingredients, except water. Some types of margarine, particularly the tough plastic type used for leafy pastry and cakes, are nearly always finished on this plant, as their structure would be damaged if treated on plant where the grinding and shearing effect is greater.

Fig. 69 is a drawing of vertical section and plan of a kneading table with a fluted wooden roller *A* of steep conical shape, that registers with the flat conical surface of the table. The position of the roller can be adjusted vertically by means of handwheel *B*, so that the distance between the surface of the table and the roller can be varied to suit the amount of material on the table and the pressure exerted on it; the position of the roller can be changed during the operation as the loose material gradually becomes consolidated. The wooden table is supported by a metal base plate and has on the underside along the rim a toothed rack *C* which is driven by a cogwheel from the driving pulley and causes the table to rotate slowly. The wooden roller is driven by spur wheel *D* off the driving shaft and has a surface speed slightly higher than the adjacent surface of the table. The loose margarine is placed on the table which when rotating brings it under the roller for compression; the flattened layer from under the roller is up-ended and partly overturned by a wooden plough *E*, whereby the direction of the pressure on the product is changed every revolution. A guide board *F* directs the rolled material from the raised rim *G* of the table towards the roller and the plough, which can be hinged away and lifted from the surface or disconnected when not required. If the margarine contains excess moisture, it can be worked out on the table by adequate pressure and will drain down the sloping surface to a circular groove at the rim, where it drains away through strainer plates and tray *H*. This kind of table is built in sizes from 5 ft. to 10 ft. diameter and requires normally 5–8 h.p. for driving.

Some kneading tables have rollers at diametrically opposite positions and no turnover plough; they are used for tough-textured products and they usually have deeper and wider grooves.

A similar horizontal revolving table, but with a different construction of roller is the Paddle Kneading Table. The roller is studded with a number of paddles or shovels, slightly out of alignment, which when the roller revolves press into the margarine and give it a mixing and kneading treatment similar to the original hand-kneading and pounding of butter. Fig. 70 shows a drawing of a vertical section and plan view of such a table. *A* is the framework carrying the wooden table *B*, that slopes slightly from the centre towards the periphery and has underneath a toothed circular rack *C*. The table revolves round the central column *D*, with ballbearing *E*, and carried

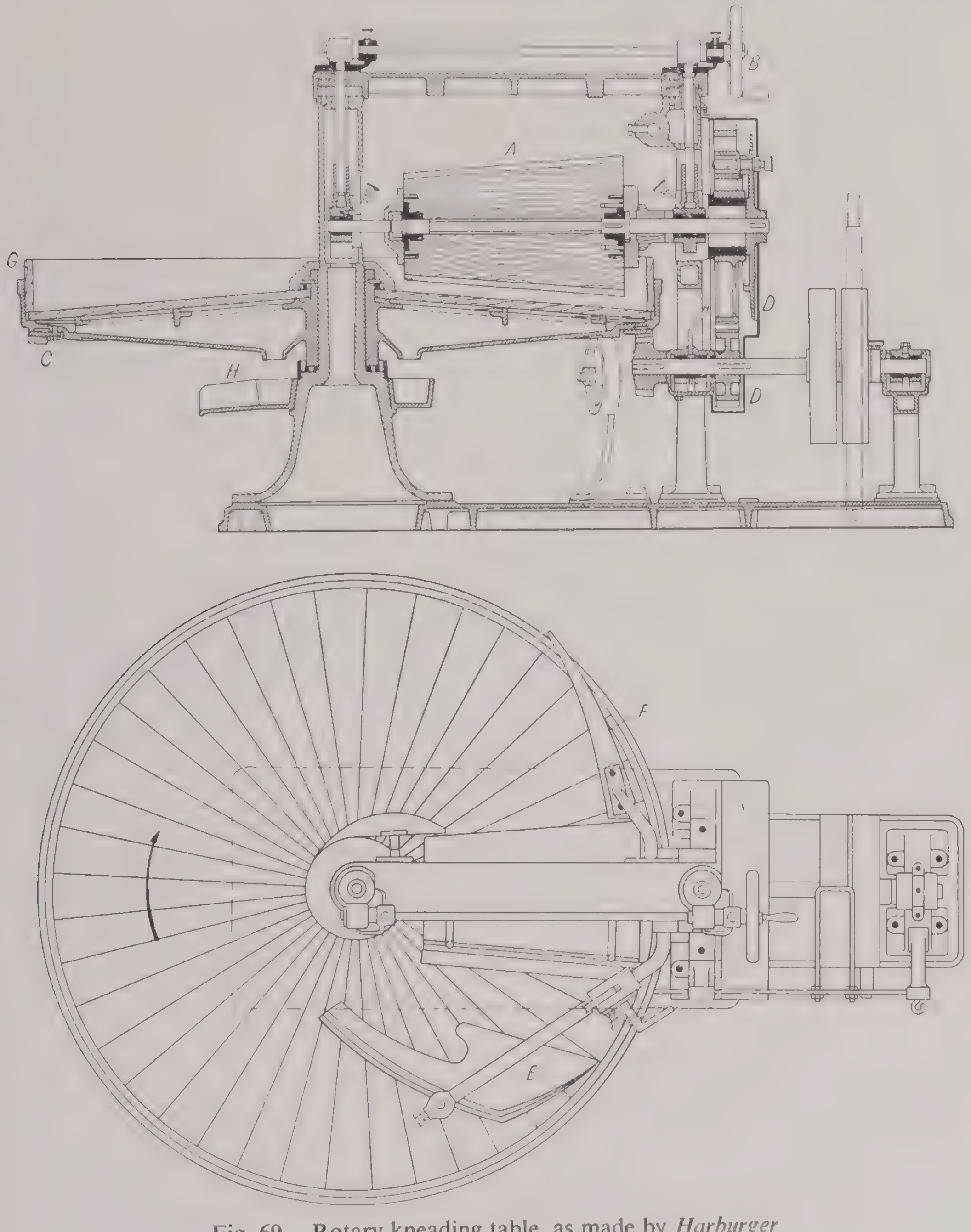


Fig. 69. Rotary kneading table, as made by *Harburger Eisen- & Bronzewerke A.G.*

by the base-plate *F*. On the central column is fixed a curved board *G*, to guide the margarine under the paddles. The motor *H* drives via coupling *K* a helical gear *I*, carried by base-plate *F*, which by cogwheel *N*, and tooth rack *C*, causes the table to revolve. Above the table on one side is the flexibly suspended rotating kneading roller *L*, which is driven by cogwheel transmission from the helical reduction gear and has on the surface a number of beaters or paddles *M*, fixed in a rather scattered pattern. Two conical guide rollers *O* support the table and take up the pressure on the table from the paddle roller. The machine has near the roller two guard boards *P* to which is joined a stationary guard rim *Q*, that prevents material from falling off the revolving table. This guard rim is missing or removable for part of the

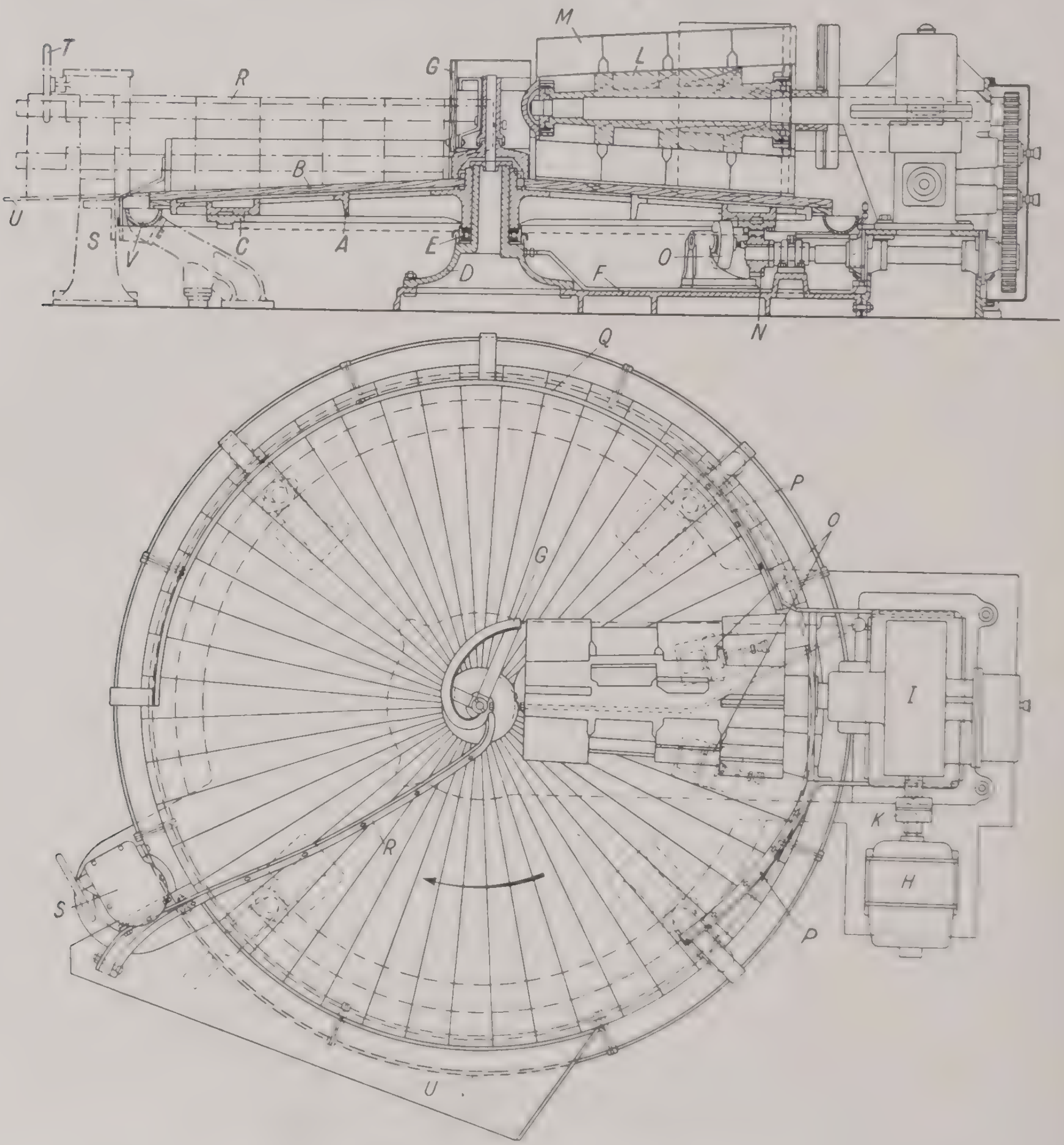


Fig. 70. Drawing of paddle kneading table, as made by *Bergedorfer Eisenwerke A.G.*

circumference, where the mechanical unloading device *R* is placed, rotatable round the pivot column *S*, by means of handhweel *T*. When emptying the table, this device is swung in across the table surface and causes the material to slide out over the edge, where the rim is missing, and down into trucks via the metal guide plate *U*. If excess moisture is pressed out during the operation, it drains down the sloping surface to the channel *V*, from which it reaches several drain pipes to the floor.

The paddle table is a very efficient machine both for consolidating loose margarine from the cooling plant and for homogenizing roller-treated margarine, and by many manufacturers it is preferred to the roller-kneading table. Some types of margarine, consisting essentially of animal fats and semi-hydrogenated fats, can be made sufficiently uniform in appearance and consistency to be ready for packing, if an extremely fine dispersion of the water phase is not essential; paddle table treatment tends to give coarser water droplets in the emulsion. By placing the table a suitable height above the floor for mechanical discharge into trucks and by arranging mechanical filling of the table, labour costs, which are otherwise high, can be much reduced. Tables are usually of 7–10 ft. diameter and require from 4 to 10 h.p. for driving.

Fig. 71 is a photograph of a table in operation and arranged for high-level working. In the background is seen the end-roller and scraper bar of the belt conveyor, that has conveyed the margarine to the table; in the front is the gap in the rim-guard, through which the treated margarine is discharged into trucks underneath by a pivoted bar swung across the table surface. The table top is of stainless steel, but the best kneading effect is obtained when both table top and paddle roller are made of close-grained hardwood, although that material increased the risk of bacterial infection of the margarine. Where the table is used for giving the final treatment before packing, only wood will give the uniformity and finish required.

Blenders and Mixing Machines.—With exception of those margarines that are made by the so-called continuous processes, as described later, nearly all table and household qualities, after undergoing a consolidation and kneading treatment on rollers or tables, are given a final working and plasticizing in high-speed mixing machines, usually known as Blenders or Mixers. The system under which they work ensures for each batch a perfectly uniform product and enables the manufacturer to adjust and standardize the quality as regards water and salt content and to incorporate sundry ingredients.

As there is in most countries a statutory maximum amount of moisture in margarine, usually 16 per cent, and as for economical reasons manufacturers wish to approach that within 0·1–0·2 per cent, the treatment in the blender affords an opportunity of doing so. Rollers and tables do not allow control of operation within such narrow limits of moisture, and to avoid the risk of exceeding the statutory limit the average moisture content after the preliminary kneading is rarely above 15–15·5 per cent. The manufacturer can then, if he so wishes, add a small quantity in the blender. More than 1·5–2 per cent water should, however, not be added in this manner, as its dispersion in the solid material is rarely in the same globular form as the aqueous phase from the original emulsion; it is mostly found as films or coarser droplets, and too high a proportion may cause the margarine to "weep" during cool storage. If salt or preservatives are added at this stage they should be in extremely fine powdery form; many manufacturers prefer to add them dissolved in water. Sometimes lecithin is added in the blender and should then be in diluted form with a non-drying oil such as groundnut oil, to make it less viscous for easier dispersion, but it is preferable to add this ingredient at the churning stage or to the fat-blend.

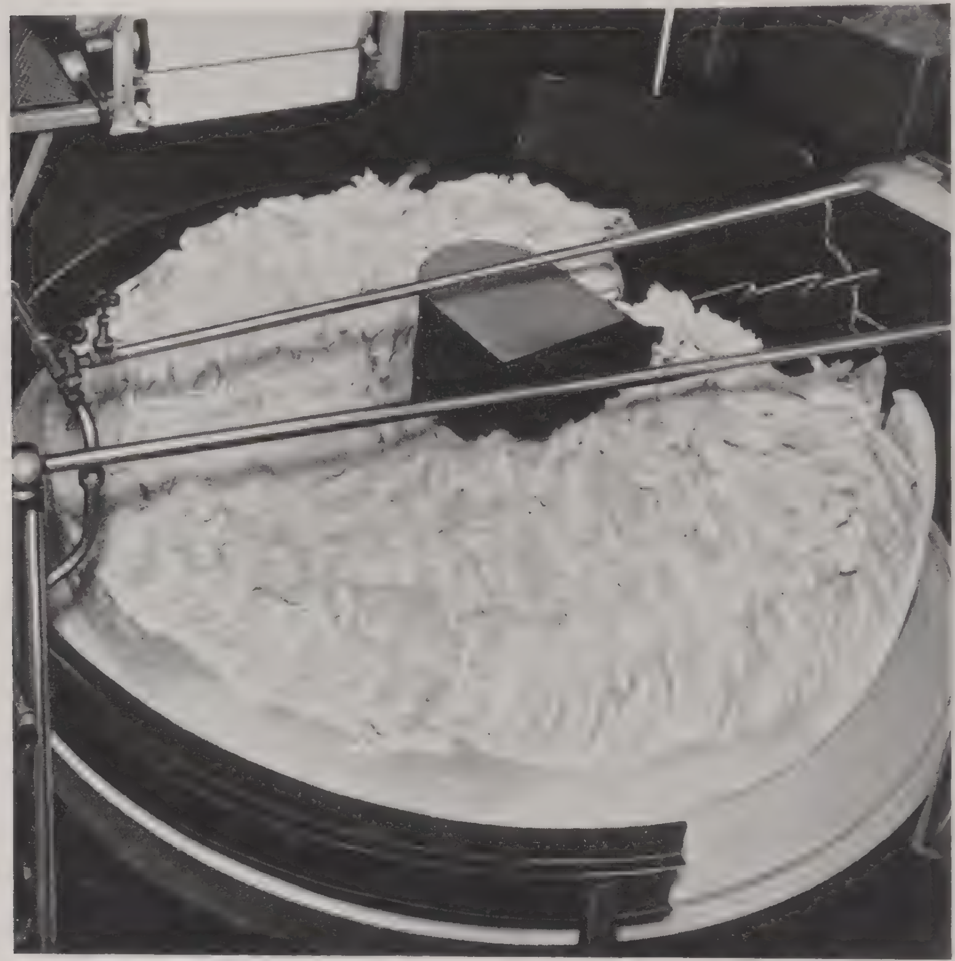


Fig. 71. Paddle table in operation (Courtesy: *Van den Berghs and Jurgens Ltd.*).

Blenders are horizontal trough-shaped machines with semi-circular bottom and removable sliding or hinged lid. They are provided with two twisted paddles or beaters of horizontal Z-shape, which revolve in opposite directions at high differential speed. The charge of margarine takes up 60–70 per cent of the blender volume, and as the result of the high-speed mixing with its pronounced kneading and shearing action, when the rapidly revolving beaters tear through the two slowly rotating blocks of margarine, a good deal of air, 10–12 per cent, is creamed into the product, with consequent increase in volume, unless the blender is constructed to operate under vacuum, which is mostly the case in modern works. The presence of creamed-in air entails a risk of bacterial infection from the air and of a slow oxidation effect of the finely dispersed air in the fat. It has also a tendency to give a dull appearance to the margarine, compared with the bright glossy appearance of the vacuum-blended quality.

Blenders are constructed in sizes from 60–1200 pounds working capacities; the smaller are filled by hand, the larger by mechanical means. Trough and paddles are usually of heavily tinned steel or stainless steel, but some manufacturers prefer these machines made of wood to avoid the risk of the margarine absorbing a metallic flavour through the friction and smearing at high speed against metallic surfaces, or of parts of the product being overworked through incomplete emptying as the result of adhesion to the metal, and thereby showing streakiness in the finished product. Machines with wooden troughs are therefore still built by several makers and in sizes up to 550 pounds working capacity.

The trough rests in horizontal bearings round which it can be tilted without disengaging the stirrers, so that when swung round 120–180 degrees to the emptying position these, though stopped while the trough is being tilted, can assist in discharging the contents. They are fitted to work close to the ends and bottom of the trough to ensure uniform working of a batch. The trough is counterbalanced for easy pivoting round the bearings; in the smaller units the tilting is done by a hand-lever, in the larger units often by handwheel and worm-gear or by a hydraulic mechanism. Some machines, owing to local safety regulations, are so arranged that they can only be operated in working position when the lid is on.

Though the plant manufacturers frequently indicate the speed at which the paddles should revolve, it is an advantage to have variable speed drive, as the amount of working, to give the product the desired finish, depends on the size of the charge, its composition, the thoroughness of the previous kneading, the kind and quantity of additions in the blender, and on the temperature in relation to the composition; some blenders are jacketed for temperature regulation. The duration of the operation is very short, about 1 minute with the small machines, 2–3 minutes with the large ones, but this has to be adjusted to all the other conditions, as a few seconds more or less may make the difference between unfinished and over-treated margarine. Examples from practice of speed ratios of fast and slow paddles are 400 and 240 r.p.m., 530 and 330 r.p.m., 600 and 345 r.p.m. for blenders with charges of 1–1·5 cwts per filling; for large blenders with charges of 10–15 cwts low speed ratios of 145 to 95 r.p.m. and high speed ratios of 255 to 170 are often used. Some manufacturers work the margarine first at the lower speed and give a final blending at the higher speed.

Fig. 72*A* and *B* shows a belt-driven blender with a working capacity of 100–110 pounds, while the volume of the trough is about 19 gallons, 85 litres. *A* is the upright operating position with the lid closed, *B* is the position with the trough tilted over for emptying and the lid hinged back. The illustration indicates the peculiar twisted shape of the paddles, which experience has shown to be particularly suited to this type of kneading and blending. The stuffing box and glands, where the paddle shafts pass through the ends of the trough, are specially designed to withstand penetration of lubricant or margarine.

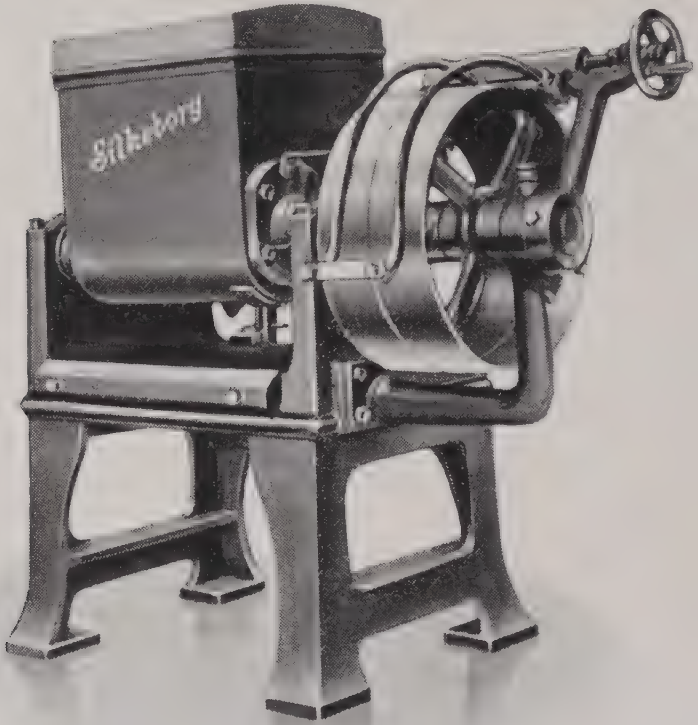


Fig. 72*A*. Margarine blender (Courtesy: *Silkeborg Engineering Works*).

Fig. 73 illustrates a blender of 2 cwts working charge, arranged for operating under vacuum; the hinged lid on which is placed a vacuum gauge is held tight by clips, and the trough, which can be tilted by means of a hand-lever after disconnection of the flexible tube to the vacuum system, is counterbalanced for easier tilting.

Fig. 74 is a photograph of a 10 cwts vacuum blender under working. To the left is seen the mouthpiece of a worm extruder from a feeding hopper above. The hinged cover of the extrusion orifice, when in the "open" position shown in the picture, acts as a chute to guide the material into the blender, which is shown nearly fully charged. The hinged domed cover, that is swung up during filling, has a packing gasket round the edge to ensure tight fitting when it is put on the blender, and has a flexible tube attached to the dome for connecting to the vacuum system. The machine is driven by a variable speed motor and runs at slow speed while filling with the margarine and ingredients or water is added. Some seconds after the lid is fixed in position the speed is increased and the mixing finished at high speed in course of 2–3 minutes, with the slow paddle running at 160–180 r.p.m., the fast paddle about 1·5 times as fast. When the operation is finished the vacuum is broken and the lid hinged back; the trough is tilted by hydraulic or other mechanical means round its own axis to enable the contents to fall into transport containers below the operating platform. During emptying the paddles are turned a few turns to assist in the removal of the plastic product.

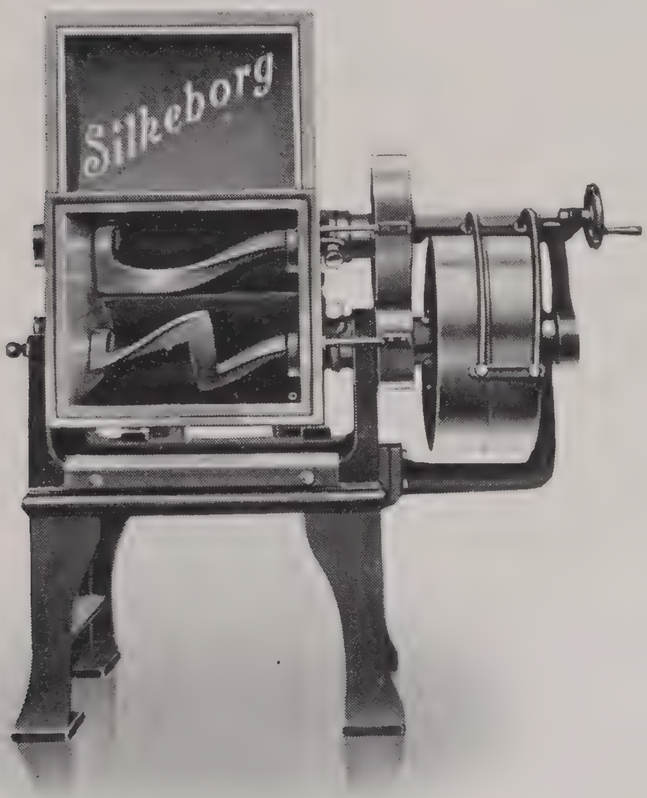


FIG. 72*B*.

Blenders are very efficient mixers when used under the right conditions; they are sometimes used for mixing margarines of different types or, where margarines containing a proportion of butter are required, to mix margarine and butter. Some manufacturers prefer, for technical and organisational reason, to churn and cool a few basic qualities and mix these in various proportions in blenders to give a greater number of final qualities of different compositions, costs and characters. In such cases it is advisable, in order to obtain the desired uniformity and consistency, to ensure that the constituents before mixing have approximately the same firmness, for example by preliminary working on rollers or table or by giving the firmer constituent a short treatment in the blender before adding the softer one. To mix two products of widely differing firmness in a high-speed blender often leads to spotted appearance and lumpy or grainy texture.

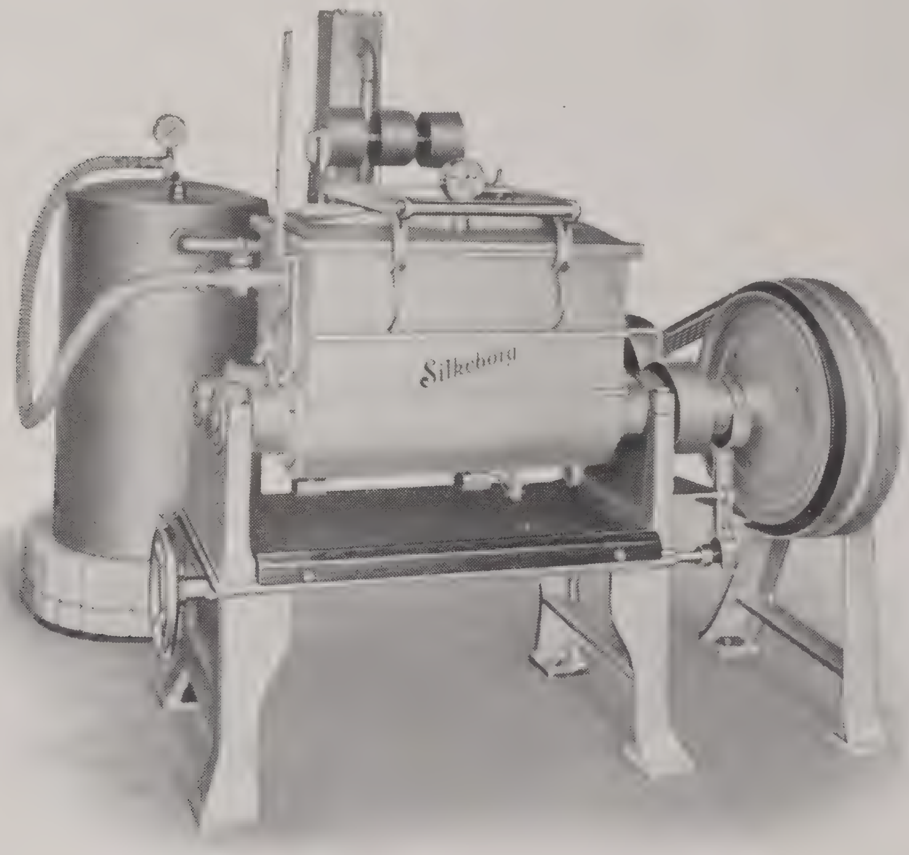


Fig. 73. Margarine vacuum blender (Courtesy: *Silkeborg Engineering Works*).

After blending, the margarine is ready for packing and, if required for bulk-packing, can be dealt with immediately. If required for packing in small packages, in U.S.A. usually termed prints, it is in most cases advantageous and customary to give it a short rest period in cool rooms, 10–12 C, to enable it to firm up after the softening effect of blending, before treating it in automatic moulding and wrapping machinery. Some manufacturers of automatic machinery claim that their plants will deal efficiently with soft margarines, but in view of the further mechanical working and compression, which it is subjected to in some types of automatic moulding and wrapping plant, it

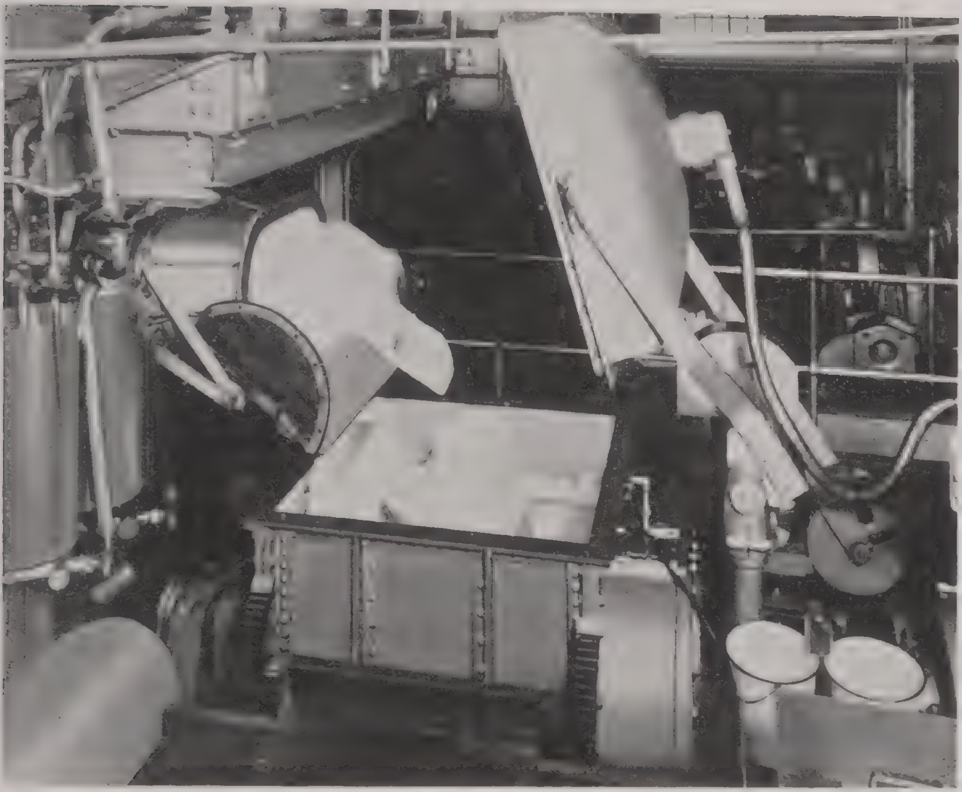


Fig. 74. Large vacuum blender in operation
(Courtesy: *Van den Berghs and Jurgens Ltd.*).

often pays to have it of firmer consistency to obtain the most efficient and economical results.

Continuous Processes

There is no sharp line of demarcation between processes usually referred to as "batch" processes and those classified as continuous. Originally the manufacturing processes dealt entirely with definite limited quantities or batches in separate discontinuous steps with resting periods between. Later, with the introduction of the drum-cooling system, that necessitated a continuous supply of emulsion, continuous emulsifiers were designed, although a continuous supply of emulsion is still as frequently obtained by working several churns in staggered time cycles. The cutting short of the resting period after cooling by transporting the solidified emulsion on belt conveyors to multiplex rollers extended further the continuity of processing, but the final blending or kneading was still a separate step. By continuous process is usually meant one in which the liquid margarine mixture in substantially the final composition enters the emulsification process at the same rate as it emerges ready for packing after undergoing progressively and without static periods the sequences of emulsification, cooling, kneading and plasticizing, in one or a series of machines without intermediate manual handling.

In medium and small factories the continuous plants permit a considerable saving in labour, power, space, auxiliary equipment and possibly wastage of material. In large factories these advantages are less pronounced, partly owing to mechanization and working with large units of equipment, partly because the number of units of continuous plants required, as, at any rate at present, their capacity is limited. The question of the flexibility of some of these plants, if frequent changes of quality is necessary, and the adaptability of the continuous plant to different types of margarine must also be taken into consideration, but the many improvements, which have been, and still are being, made to these plants, are gradually causing them to compete successfully with and replace the older type of batch plant.

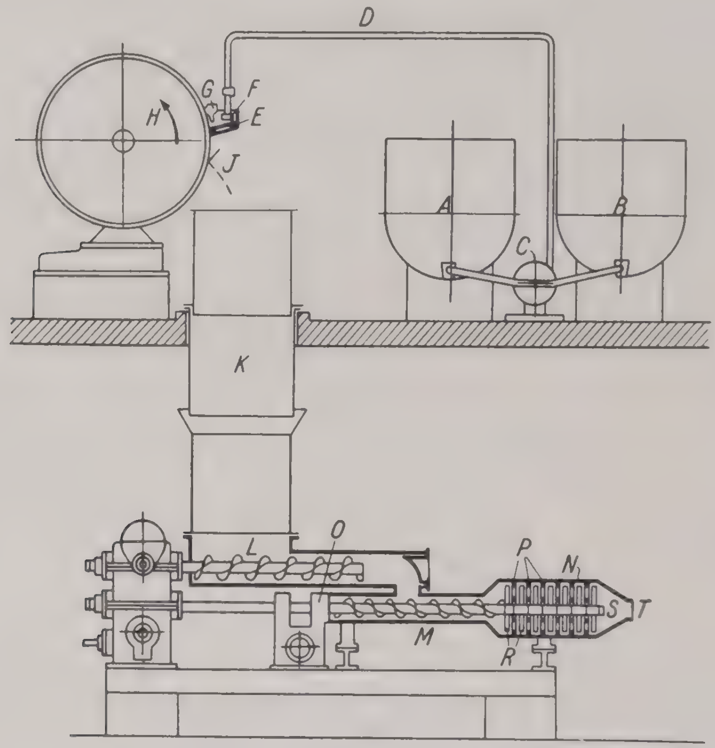


Fig. 75. Diagram of Gerstenberg vacuum Complector plant.

The Gerstenberg Complector Plant.—This plant, made by *Gerstenberg and Agger*, Copenhagen, is widely used in the margarine industry and is built in units with capacity of 0·1–4 tons per hour or more. Liquid margarine from pre-mixers passes continuously via an emulsifying machine, the Emulsator, a high-speed cooling drum, the Diacooler, to the continuous kneading and blending aggregate, the Complector, from which it is delivered in a continuous bar ready for packing.

Fig. 75 shows a diagram of a Gerstenberg plant assembly. *A* and *B* are jacketed mixing and tempering vats; the specially designed motor-driven helical agitators, fitted in these stainless steel vessels, run at 50–60 r.p.m. and ensure thorough mixing of fat-blend, milk or other aqueous phase and ingredients; the bottom slopes slightly towards the outlet to facilitate complete draining; stainless steel covers, easy to remove, prevent losses by splashing when the agitators run at full speed; steam or temperature regulated water in the jacket controls the temperature of the mixture and thus of the emulsion which is supplied to the drum. From the two mixing vats alternately the mixture runs to the Emulsator *C*, that serves as a combined emulsifying machine and pump for passing the emulsion to the feeding trough for the Diacooler; stainless steel is used for all parts coming in contact with the emulsion, and the Emulsator is specially constructed for easy dismantling for cleaning and sterilizing. Through pipeline *D* the emulsion reaches the jacketed temperature controlled feeding trough *E*, where the level of the emulsion is controlled by the float *F*, that regulates the opening of the supply valve. The horizontal bar *G*, the distance of which from the drum surface can be adjusted, controls the thickness of the layer of emulsion applied to the surface of the drum that forms one of the sides of the trough. The drum *H*, which is now usually made of steel with stainless steel or hard chromium coating on the cylindrical surface, revolves at 60–70 r.p.m. and solidifies the thin film of emulsion in course of nearly one revolution. A scraper knife *J* placed close under the feeding trough (see also Fig. 57) removes the solidified emulsion as a sheet, which breaks up into smaller flakes and coarse powder when falling into the silo or hopper *K* below, where crystallization is largely finished and supercooling released. At the bottom of the hopper, that is dimensioned to hold a few minutes' to half-an-hour's supply to permit the temperature to rise to 7–8°C and some stabilization to take place, the product enters a worm conveyor *L*, consisting of two parallel screws, driven by independent gearing, which mixes, agregates and compacts the loose material and drops it into a second conveyor worm *M*, consisting of one screw co-axial with the kneading element *N*. At the driving end *O* of the lower worm conveyor is a connection to a vacuum plant, so that the part *M* of the Complector is under reduced pressure, in accordance with the Gerstenberg patent [167], which largely prevents air in the loose product from being kneaded and creamed into the consolidated product and cause unevenness and mottled appearance; a reduced pressure of about 380 mm mercury is usually kept at this point. The conveyor worm *M* forces the margarine into the Complector kneading and plasticizing section *N*, a cylindrical tube of wider diameter than, but co-axial with, worm *M* and fitted with a number of fixed orifice plates *P*, through which the margarine is pressed; the orifices vary in shapes, but are mostly crescent-shaped. In front of and between each orifice plate are revolving knives *R*, fixed on the rotating shaft, the blades being set at an angle to the fixed plate and cutting closely against it. This intensive treatment of cutting, shearing, working and extruding the margarine through the many orifices, 8 in each plate gives a strong blending and plasticizing effect. The cylindrical kneading section is followed by a short conical section *S* where the margarine is compressed and consolidated into a compact bar that is extruded through a circular or rectangular nozzle *T* and is then ready for packing.

The Diacooler with its high speed and very thin film of emulsion, 0·1 mm or less, which enables the crystallization to be practically completed on the drum, should preferably be used with a "thin" easy-flowing emulsion, that also occludes a minimum amount of air. The temperature in the mixing vats *A* and *B* should be regulated accordingly, depending on the fat-blend, but for many blends it is advantageous to adopt the emulsification technique, described in the chapter on Churning, of formation of microscopical crystal centres or nuclei, which once established will persist even if the temperature of the mixture is raised to 35–38°C, as is often the case, to reduce the viscosity; any "loosening" of the emulsion which the increase in temperature might tend to cause is eliminated by the passage through the Emulsator. The formation of nuclei and the small degree of supercooling, resulting from the high speed of the drum, will help to create suitable conditions for such post-cooling crystallization as is necessary for stabilization, in spite of the relatively short interval between cooling and kneading. Conditions for kneading and blending are also improved by the rise in temperature that takes place in the silo *K* and in the Complector by internal heating of the hollow shafts for worms *L* and *M* and kneading section *N*. In some plants the fixed kneading elements can also be heated; water, or now more frequently oil, is used as heating medium and is heated in a separate small tank to a temperature which is adjusted to suit the composition of the fat-blend, the supercooling effect, the time interval, and hence the temperature rise, in the silo and the degree of working in the Complector section *N*. Temperatures of the heating medium of 15–35°C are used, but in no case should the temperature be above the melting point of the margarine. The mechanical working, to which the margarine is subjected in the Complector, can be varied by varying the number of orifice plates and cutters in section *N*, which is built up of a variable number of sections carried on external sliding-bars. Many factories work with a dozen orifice plates and a dozen knives, but both a smaller and larger number is often used. The effect can also be varied by changing the rotation speed of the kneading elements, which usually revolve at 140–170 r.p.m., and the amount passed through per unit time, that can be regulated by altering the rotation ratio between the feed-conveyor *L* and sections *M* amd *N*; for example, the double worm conveyor *L* may rotate at 25 r.p.m., while the lower shaft rotates at 150 r.p.m. The relative diameters of the conveyor tubes also vary in different plants, the tube *M* being usually smaller than the compacting tube *L*, for example 7 in. against 8 in. with about 10 in. in the kneading section.

It will be seen that there are a number of variables that can be adjusted to suit circumstances, and under the correct conditions as to temperature, through-put and mechanical working the margarine leaves the plant in softish and plastic consistency, but stabilized as regards crystallization, as is indicated by the issuing product showing no change in temperature during the rapid firming up to a consistency, which permits packing in bulk or in automatic moulding and wrapping machines. A table margarine of average composition will show a temperature of 13-15°C after correct treatment.

The Complector is mostly built of stainless steel; in some cases the body is of cadmium-treated steel. A rather powerful motor is required for driving, a 3·5 tons per hour unit about 50 h.p., a 1·5 tons per hour unit about 30 h.p. The length of the Complector aggregate is 8–15 ft. Units working up to 7 tons per hour are in operation; in such large installations two or more Diacoolers supply the solidified flaky emulsion via conveyor belts to the silo.

In some factories a different arrangement is used for supplying the loose margarine from the silo to the Complector. In these cases two parallel horizontal steel rolls, 8-15 in. in diameter according to the size of the plant, are placed at the bottom of the silo, with about 1 in. distance between the faces of the rolls; these rotate slowly at the same speed in opposite directions in intermittent movements through 20–30 degrees, the distance and thus the number of full revolutions per minute being controlled by an adjustable ratchet arrangement off the main drive, which thereby regulates the input to the Complector; the rolls are fitted with scraper blades to prevent adhesion of the cold margarine, and in some plants they are provided with means for circulation of water for mild warming. In plants fitted with rolls the upper conveyor and compacting worm of the Complector consists usually of a single screw rotating at about 55 r.p.m. with the lower narrower screw and the cutting knives rotating at about 150 r.p.m.

Fig. 76 is an illustration of a Gerstenberg Diacooler and Complector installation. The cooling drum is on the upper floor and the hopper silo passes through the floor to the Complector aggregate underneath; the above mentioned feeding rolls are seen at the bottom of the hopper, on top of the single upper worm tube; behind the rolls can be seen the lever arm of the adjustable ratchet mechanism. The horizontal cylinder under the upper worm tube, provided with manometer, is a vacuum tank, connecting to the vacuum pump and to the rear end of the lower worm. In this particular installation the compression piece and outlet from the kneading elements direct the extruded margarine slightly upwards into a truck.

The Diacooler and Complector are in some factories used in conjunction with already existing emulsion churns, which is quite satisfactory, as churns normally make it possible to adjust the emulsion to the type most suitable for the Diacooler and Complector; the use of the Emulsator is then superfluous, provided two or more churns can work on time cycles ensuring a continuous supply of emulsion to the drum.

There are also places, where the Complector aggregate is used as a continuous kneading and blending plant for margarine churned by the conventional method and cooled on the more slowly revolving drums of the types cooled by brine or direct expanding ammonia, as described on pages 173–179. Owing to the thicker film of emulsion and the longer exposure to the cooling effect on the drum surface the solidified product is in a more supercooled state and requires some rest interval for supercooling to be released and crystallization to be advanced, accompanied by temperature increase; it is therefore usually kept in containers or trucks for 0·5–2 hours' rest and stabilization, before submitting it to the continuous kneading and blending in the Complector. Alternatively it can be conveyed slowly in a thin layer on a belt over a distance of 30 ft. or more before being dropped into the hopper for the Complector, the thin layer enabling the stabilization to proceed more rapidly than in bulk containers. Even when using the Diacooler solidification system several manufacturers prefer to extend the interval between cooling and treatment in the Complector, and effect this by a belt conveyor stage between the two process steps, and conveyors of up to 50–100 ft. are used occasionally, where this is convenient for the lay-out. Such an arrangement gives an ample safety factor as regards crystallization stabilization for widely varying compositions, but it is more costly, and it loses the simplicity and compactness of the standard lay-out.

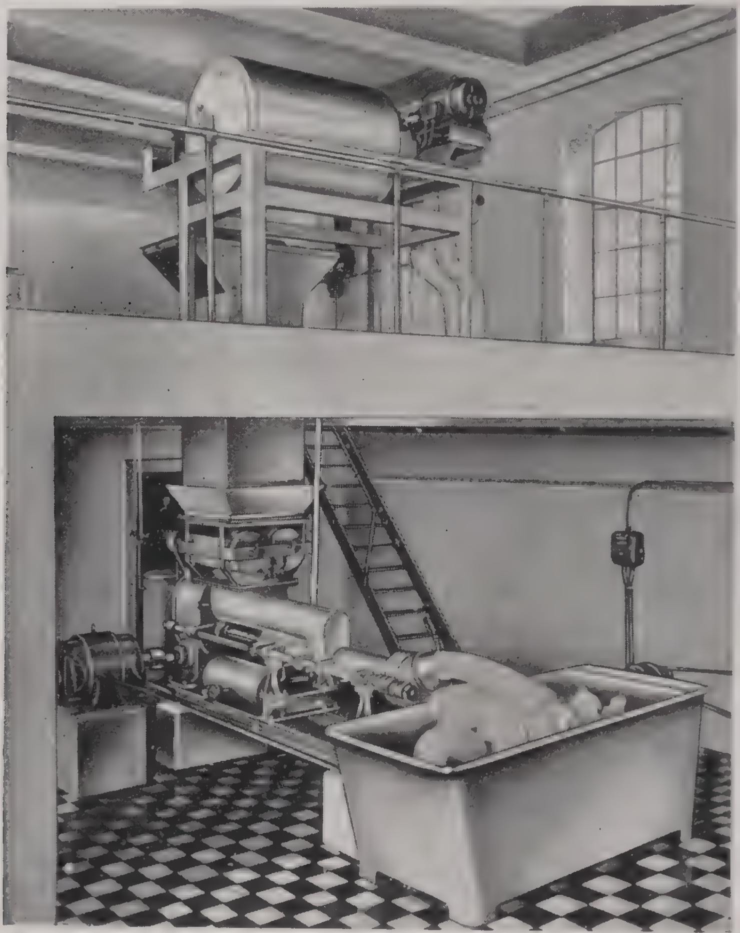


Fig. 76. Gerstenberg plant installation (Courtesy: *Gerstenberg and Agger, Copenhagen*).

The Schröder Plant made by *Schröder and Co., Lübeck*, works on similar principles but differs in certain details of construction; it is made of capaci ties from 400 kg to 5 tons per hour output, and includes churns or emulsifiers for supplying continuously the liquid emulsion to a single cylinder cooling drum for the type mentioned on page 176, but arranged for direct ammonia expansion and frequently also with a semi-cylindrical metal shield covering the upper half of the cooling surface (see Fig. 77*A*). The solidified film of margarine is removed by a scraper fixed close below the feeding trough, so that nearly the whole cylindrical surface is available for cooling. According to the lay-out of the factory there are different arrangements for conveying the flakes of margarine to the vacuum kneading plant; the plant manufacturers do not recommend the direct dropping of the flakes into the kneader. Where a multi-storied building is available a lay-out as shown in Fig. 77 is suitable; in this case the flakes fall from the cooling drum, which is placed on the upper floor, into a silo placed in an opening in the floor. This silo is provided with a screw conveyor at the bottom, discharging the material into the funnel

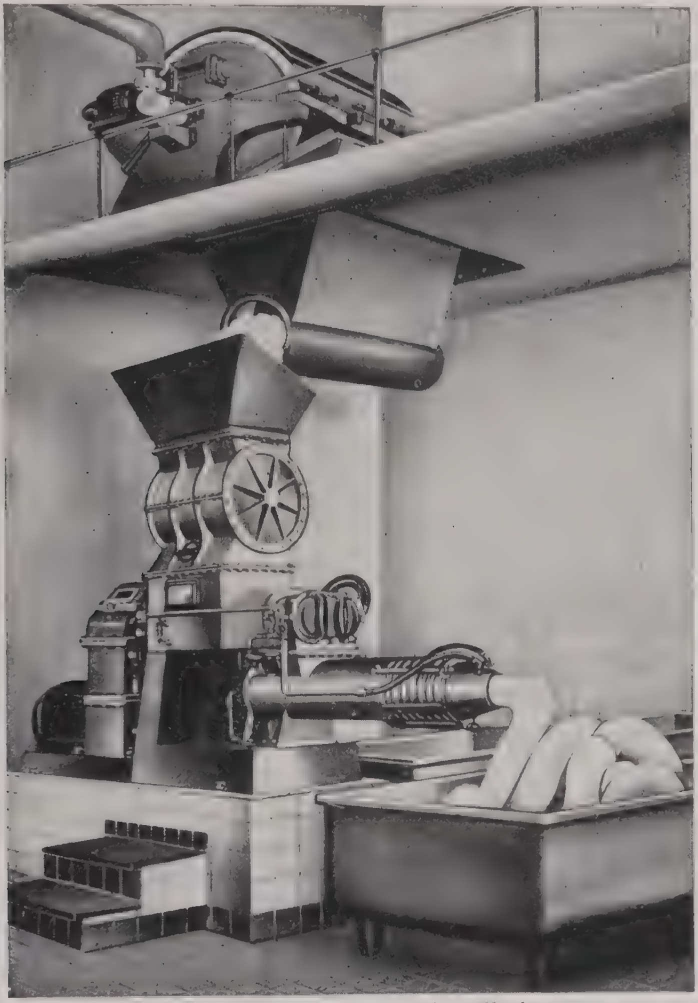


Fig. 77. Schröder plant installation (Courtesy: *Schröder & Co., Lübeck*).

for the kneading machine, and dimensioned to give the flakes about 20 minutes' rest for stabilization of crystallization. If the lay-out is in a single story an arrangement on the lines of flow-diagram Fig. 78 is recommended. From the scraper the flakes fall on to a short belt conveyor C_1 that takes them away from the drum position and deposits them on another belt C_2, which slopes upwards and deposits them on a third belt C_3, for lifting and discharging them into the funnel for the kneader. Resting the flakes in fairly thin layers on the belts, exposed to room temperature, and turning them over when dropped on the next belt, accelerates post-crystallization, and a resting period of 5 minutes before kneading is stated to suffice. The kneading machine [168] (see Fig. 79) has between the funnel *A* and the kneading section a cylindrical sealing chamber or revolving sluice *B* which, when it rotates and passes the broken flakes through to the chamber below, acts as an airlock against the vacuum, that is drawn on this chamber for de-aeration of the flakes, before they are consolidated and compressed. This takes place

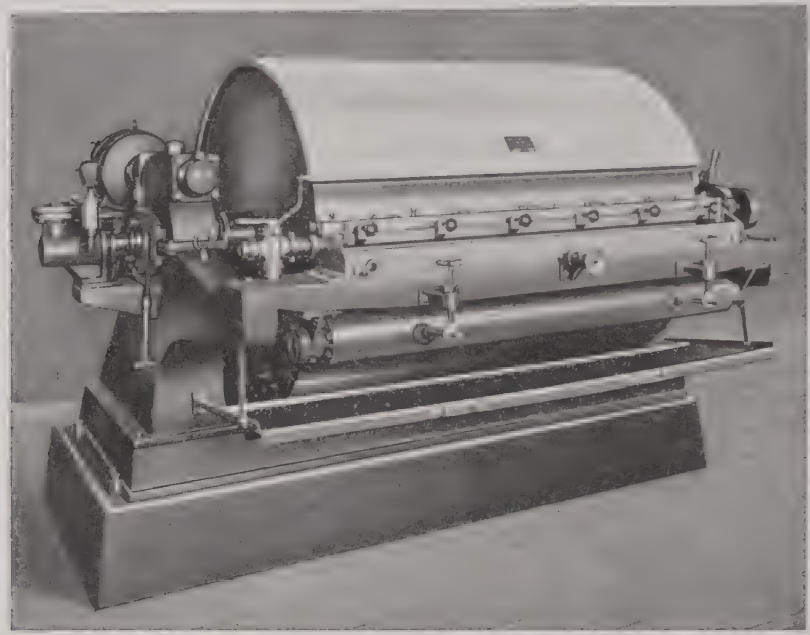


Fig. 77*A*. Schröder cooling drum for direct ammonia (Courtesy: *Schröder & Co., Lübeck*).

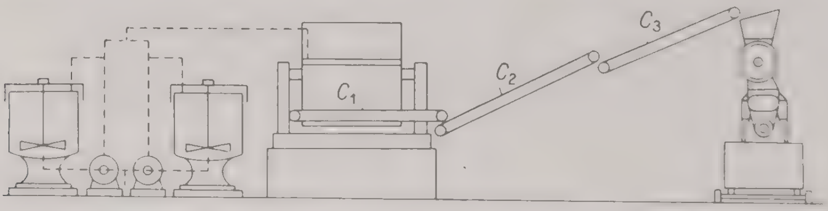


Fig. 78. Diagram of Schröder installation (Courtesy: *Schröder & Co., Lübeck*).

in sections *C* and *D* where also kneading and homogenization take place and where the treatment can be adjusted by varying the number of kneading elements. The extrusion mouthpiece *E* and other parts of the kneading section can be temperature regulated by water circulation, and the rate of throughput, and thus of kneading, can be varied by the adjustable speed of rotation of the sluice feeder. The margarine is ready for packing soon after leaving this continuous machine.

In Scandinavia a fair proportion of the margarine production is spread over a number of factories with small output, 10–15 tons per week or even less, and machinery manufacturers have designed continuous plant with low operating cost to suit local conditions. Some of these plants, by scaling up, have been adapted for larger output and also found applications in other countries. In addition to the Gerstenberg Complector plant already described mention should be made of the Silkeborg plant and the Atlas Lardin plant, which vary in some details, though employing the same principles of continuous emulsification, cooling and kneading.

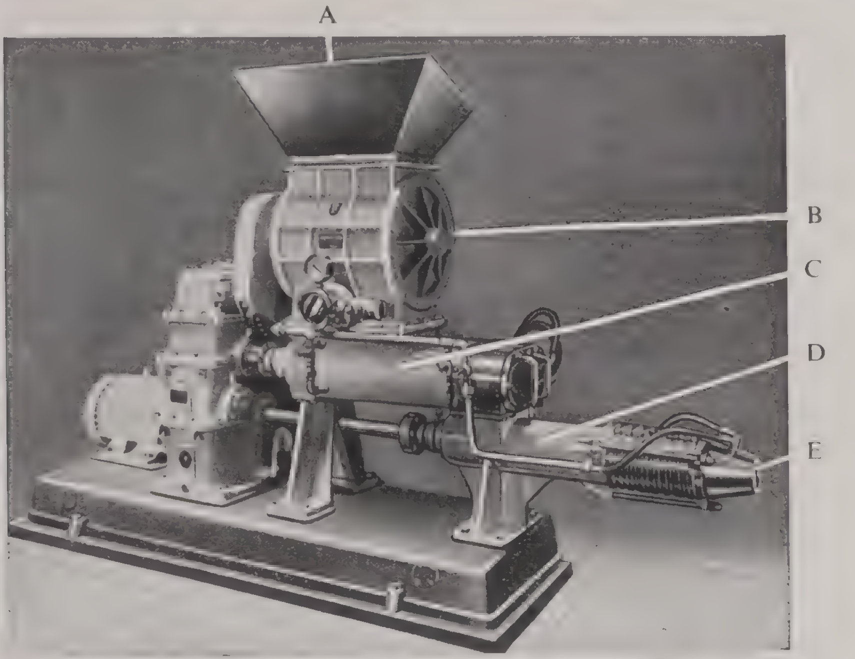


Fig. 79. Schröder continuous vacuum kneader (Courtesy: *Schröder & Co., Lübeck*).

The Silkeborg Plant, made by *Zeuthen and Larsen*, Silkeborg, Denmark, employs premixers, such as the horizontal semi-cylindrical vats of the type described on page 155, Fig. 37, and the Silkeborg continuous emulsifier, page 154, Fig. 36; the emulsion is solidified on the Silkeborg cooling drum, page 182, Fig. 55, and falls in a supercooled condition via a funnel on to a stainless steel belt conveyor, where it is held for a few minutes and increases in temperature, as supercooling is released, while the material is being transported to a special continuous kneading apparatus, the so-called Universal

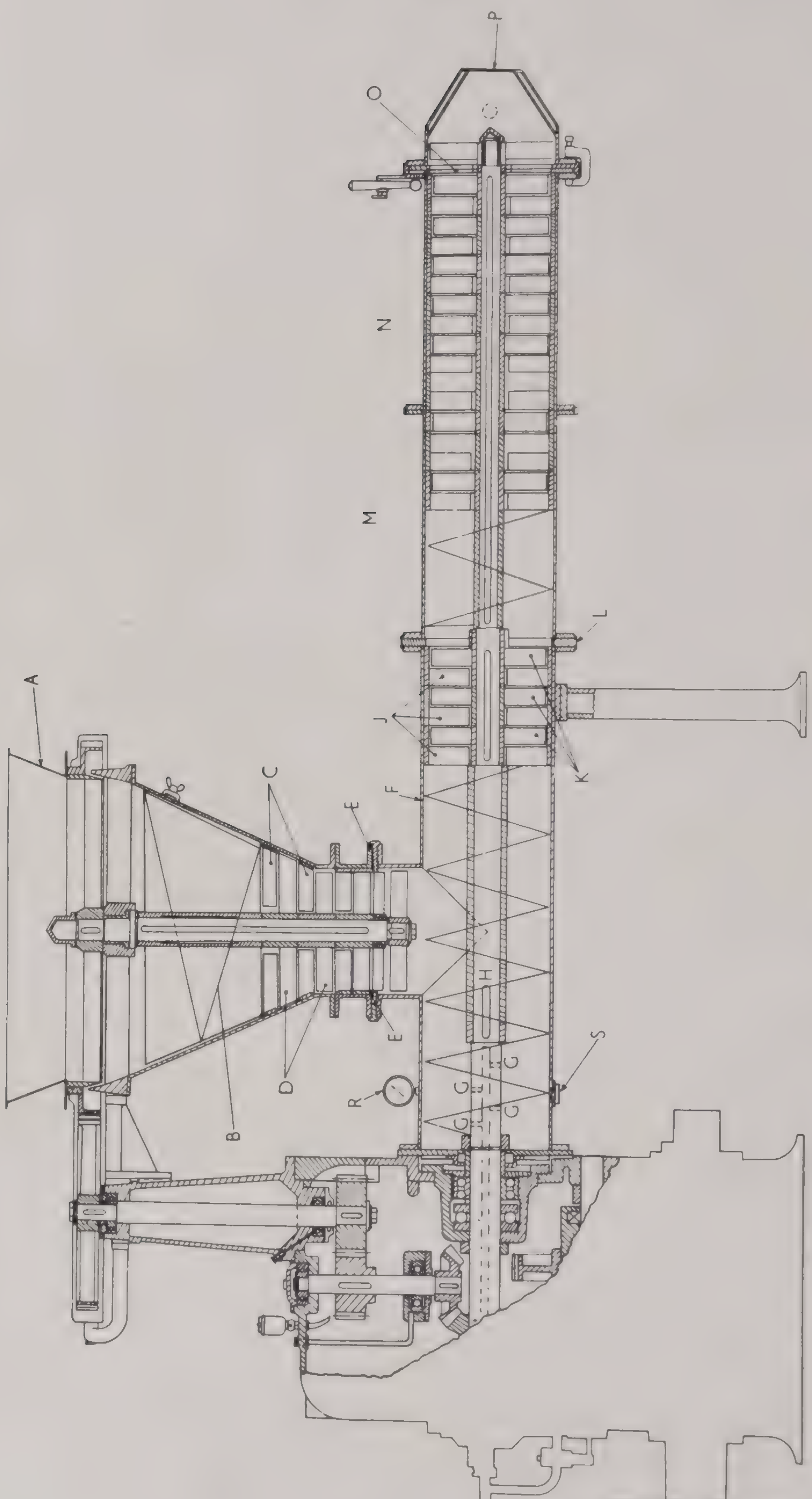

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Fig. 80. Diagram of Silkeborg Universal kneader
(Courtesy: *Silkeborg Engineering Works*).

Margarine Worker. Where, as it is often the case in smaller factories, the whole intallation is on one floor, the conveyor belt travels at an incline to deliver the loose margarine at the higher level of the receptacle for the Universal machine. This consists of a vertical feeding funnel, which delivers the compacted material into a horizontal kneading tube containing conveying and kneading elements.

Fig. 80 is a drawing of a vertical section through a Universal Worker as equipped for a typical table quality of margarine. The funnel *A* receives the loose margarine and guide plates direct this into the conical compacting chamber, where the helical conveyor *B*, fixed bars *C* and revolving propellers *D* compress the margarine towards the bottom and to the horizontal kneading section. At the bottom of the vertical feeding tube is a throttle valve *E*, by means of which the compacting pressure above can be varied to ensure that a solid block of margarine has been formed just above the throttle to act as a seal against the vacuum in the horizontal conveyor chamber just below, which is connected to the vacuum pump system. The compacted margarine passing the throttle valve falls into the horizontal kneading tube *F*, the rear part of which communicates with the vacuum system through four channels *G* leading to the hollow centre of the rear end of the shaft for the worm conveyor *H* and the kneading elements; the channels *G* are protected by baffle hoods against margarine being sucked in; a vacuum gauge *R* indicates the reduced pressure. The conveyor presses margarine from the vacuum section to the kneading zone where it is worked and plasticized by a series of alternating resistance plates and propelling cutters *J* and *K*, until it reaches a set of throttle plates *L* the apertures of which can be regulated by a handle; by adjusting the cross-sectional area of the apertures the pressure and rate of passage of the margarine can be controlled and thus the degree of kneading. A further conveying and kneading section *M* and a final kneading section *N* is shown in this arrangement, and at the end of *N* is again a throttle device *O*, through which the margarine after adequate kneading reaches the conical mouthpiece *P*, that is jacketed for circulation of water, the temperature of which varies with the season, but is generally 25–30°C. The tube for the vacuum section is provided with a removable inspection cover to enable the operator to ascertain that the exhaust system is unobstructed; if it needs cleaning out, it can be done with hot water, which can be drained off through drain plug *S*. Some margarine compositions, particularly those containing a preponderance of animal fats, require a less drastic working; in such cases some of the kneading elements in the final section are removed and replaced by distances bosses on the shaft, according to the number of elements left out. The feeding funnel, kneading tube and the shafts are normally made of stainless steel, whereas the various propelling and kneading elements are made of well-tinned special bronze. The machine aggregate is driven by electric motor or wedge-rope pulley, and via a gearbox with reduction and bevel gears the motion is transmitted to the horizontal shaft for the kneading elements and to a vertical shaft, which by cog wheel and rack drives the shaft in the compacting box; the speeds of rotation of the various parts are in fixed relationship and variations in the degree of working is achieved by the throttling plates.

Fig. 81 is a front view of a Silkeborg Universal Margarine Worker of the construction shown in section in Fig. 80. Fig. 82 is an illustration of a Silkeborg installation with mixing vessels and cooling drum in the background, conveyor belt from the drum sloping up to the feeding funnel for the kneading aggregate, and the finished margarine being delivered into a truck in the foreground.

The Atlas Lardin Plant is another example of operating units arranged to give a plant for a continuous sequence of processes from mixing of the raw materials to the delivery of the final product ready for packing. The premixing plant consists of two horizontal vats with agitators as described on page 155, Fig. 37. The mixture is given a final emulsification in a high-speed rotary emulsifier pump with special atomizing nozzle and made of stainless steel where coming in contact with the margarine. The emulsion is delivered to the feeding trough, which is placed at the highest point of the cooling drum as described on page 185, and illustrated in Fig. 58. As the scraper, which is made of special steel, is placed fairly high up on the drum to enable about 85 per cent of the surface to be utilized for cooling, the solidified emulsion is removed well above the level of the axis of the drum, and a special stainless steel funnel is fitted to catch the sheets of emulsion flakes, as they are flung out from the scraper, and guide them down to a conveyor belt for transportation to the kneading plant. The latter is known as the Mycronisator and differs in some features from those already described [169].

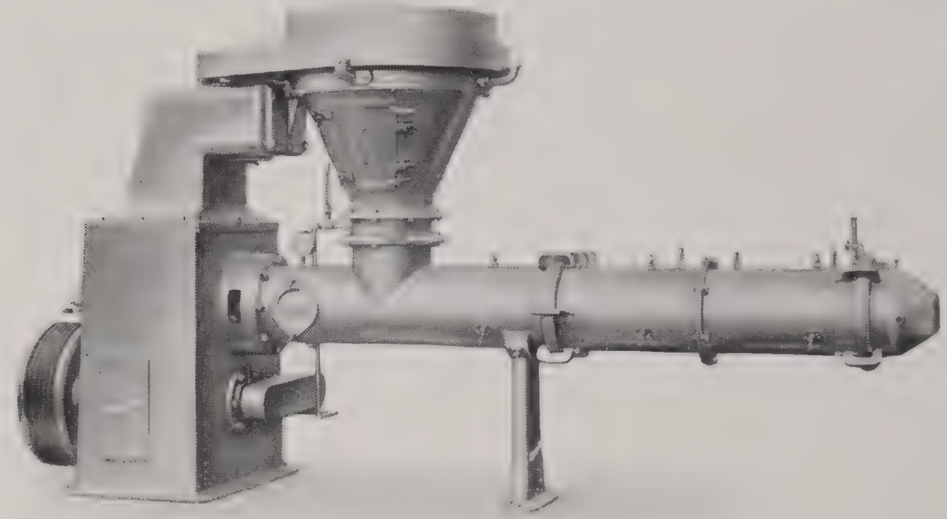

Fig. 81. View of Silkeborg Universal kneader (Courtesy: *Silkeborg Engineering Works*).

Fig. 83 is a drawing of a Mycronisator in vertical section and in plan. It consists of a housing *A* with worm *B* and kneading elements *C*; all parts in contact with margarine are made from stainless steel. Worm and kneading elements are driven by the same motor or pulley drive *D* through a gear box *E* with a differential gear, so that the shaft for the worm is kept at constant speed, whereas the shaft for the kneading elements, which is journaled in the worm shaft, can be varied in speed from that equal to the worm to three times as many revolutions per minute. In this manner the amount of working given to the margarine can be varied as required, independent of throughput.

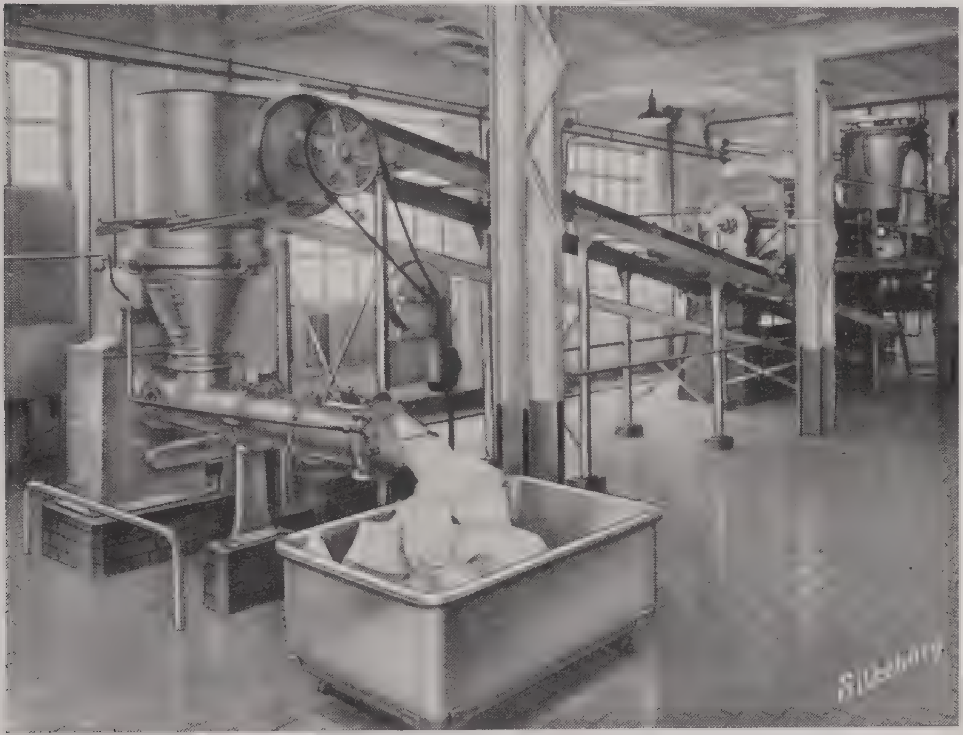

Fig. 82. View of Silkeborg installation
(Courtesy: *Silkeborg Engineering Works*).

The kneading elements consist of fixed units *F* and rotating units *G*, both kinds provided with horizontal kneading rods between which the margarine is squeezed and thus worked; this method of passing the product in a radial direction inwards is claimed to yield a homogeneous margarine free from streaks and loose moisture. Between the kneading units are propeller wheels *H* which help to cut, work and convey the margarine. The spiral blades of the worm conveyor, as well as the shaft, are hollow to permit circulation of tempered water, the inlet being at *W*, so that the margarine gets a suitable temperature for plasticizing and adhesion to the metal surfaces is minimized. The loose margarine flakes are taken by the belt conveyor to the funnel for delivery into the Mycronisator at the inlet *I* to housing *A*; they are compacted to some extent by the worm conveyor before reaching the fixed and rotating

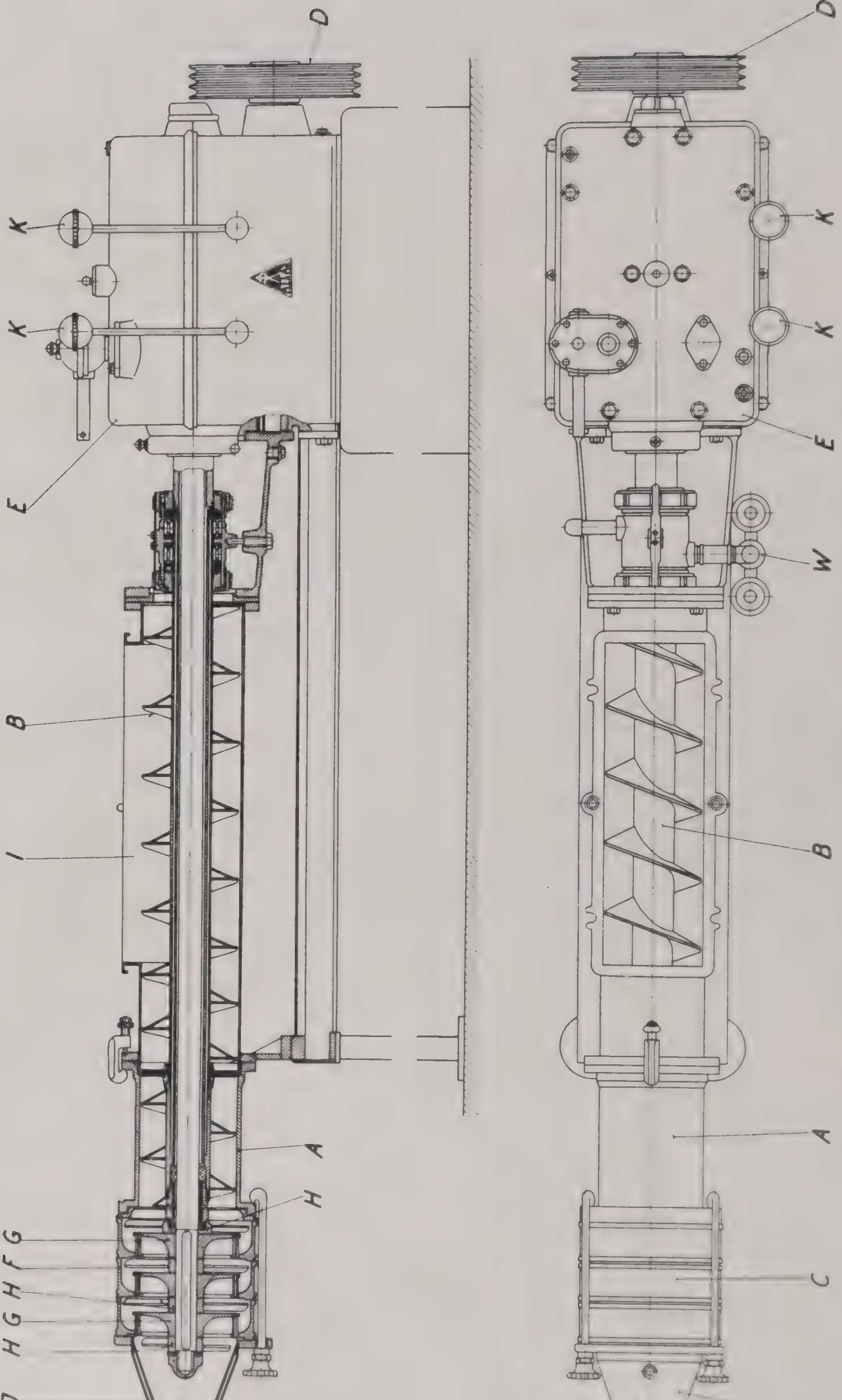
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Fig. 83. Drawing of Atlas Mycronisator (Courtesy: *Atlas A./S., Copenhagen*).

kneading elements. The product is finally compressed and extruded from the jacketed conical mouthpiece *J*. The gear levers for varying the relative speeds of worm and kneading elements terminate in the two knobs *K*. The power consumption of a Lardin plant depends naturally on the capacity; as an example, a plant for an output of 2·5 tons per hour would require 2 × 2 hp motors for the mixing vats, 10 hp for the emulsifier, 10 hp for the cooling drum and 15 hp for the Mycronizator. Fig. 84 is a photograph of an Atlas Lardin Plant, showing in the background a mixing vat, the cooling drum and the funnel, broader at the top to match the length of the drum and narrower at the bottom to suit the width of the conveyor belt; the latter is seen fitted to deliver the loose margarine into the funnel for the Mycronizator in the foreground.

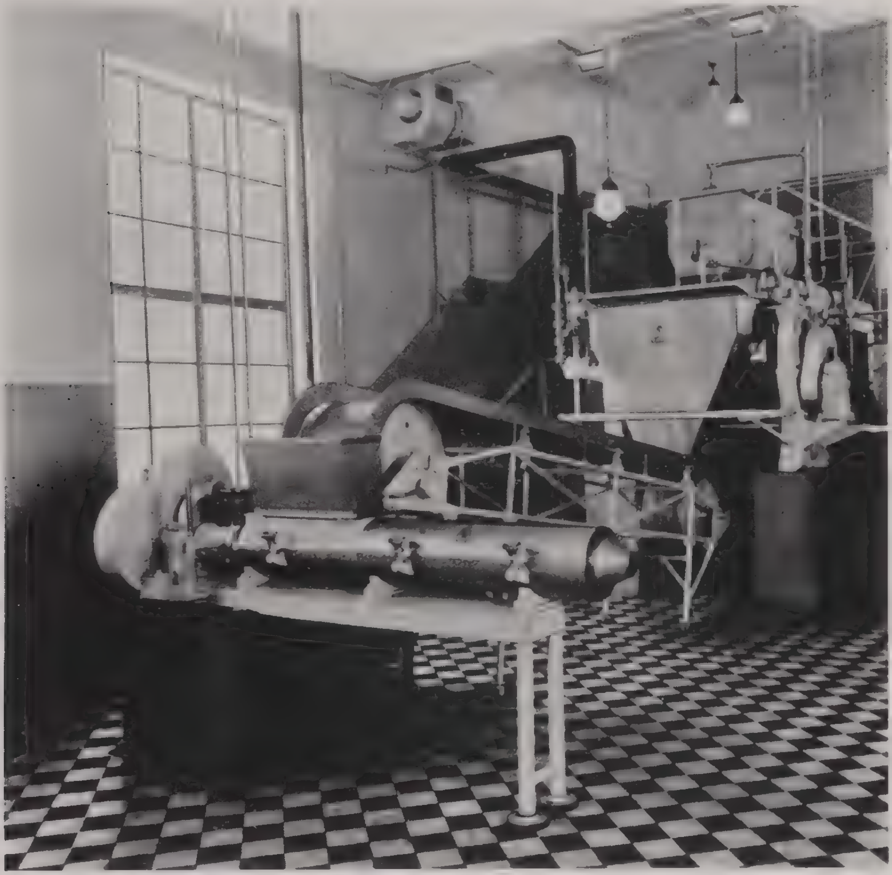

Fig. 84. (422) Lardin plant installation (Courtesy: *Atlas A./S., Copenhagen*).

The continuous plants described so far, have consisted of a number of units for carrying out the various process steps in a continuous sequence. Another type is the Tubular Cooler Plant, in which the processes are carried out practically simultaneously in a closed system, the main section of the plant being used for emulsification, cooling and plasticizing. The first practical and most widely used plant was introduced by the Girdler Corporation of U.S.A. under the name

Margarine Votator.—The Votator is a heat-exchanger with a large heat transfer surface relative to the volume of material under treatment, and the total coefficient of transfer is high as the result of the velocity of the material past the transfer surface and efficient removal of the insulating film at the area of transfer. It has been in extensive use for cooling and crystallizing fats such as lard, compounds and hydrogenated shortenings for a number of years and has been adapted for the same purpose on a fat-water emulsion such as margarine, where emulsification is intensified while cooling takes place.

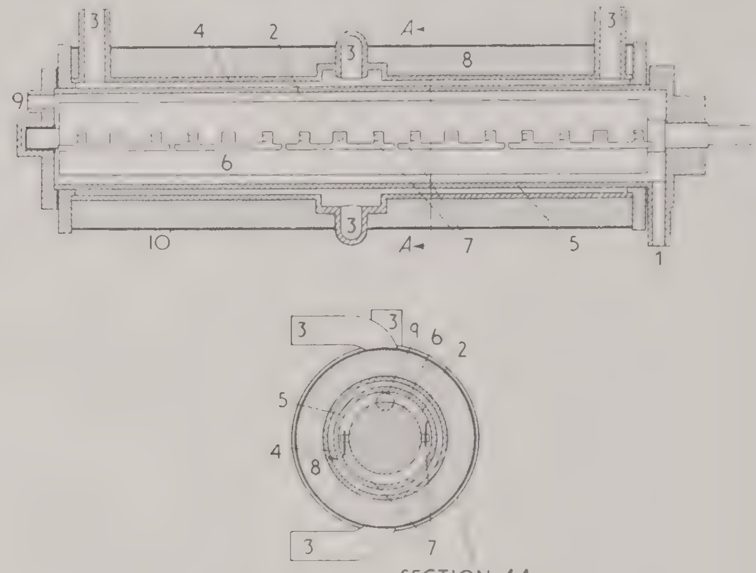

Fig. 85. Diagram of Votator cylinder (*Girdler Corp., Louisville, U.S.A.*).

Before discussing the process features, by which this method of operating differs from those previously mentioned, the principal operating unit is described with reference to Fig. 85 that shows diagrammatically the constructional principle. The liquid margarine mixture enters the Votator under high pressure through inlet *1*, to the processing cylinder with the narrow annular space *2*, between its wall *5*, and a co-axial rapidly revolving shaft, the mutator *6*, fitted with scraper blades *7*. Surrounding the processing tube *5* is an outer cylinder which provides the annular space *4*, in which the cooling medium circulates via connections *3*, to the refrigeration plant. The outlet for the cooled and partly solidified emulsion is at 9. The Votator is surrounded by a thick layer of insulation *8*, with an outer steel plate cover *10*. The product is pumped continuously through the processing cylinder under considerable pressure, 200–300 lbs. per sq. in., and while being cooled it is vigorously stirred and mixed by the scraper blades on the mutator shaft, which revolves at high speed, 400–600 r.p.m. The special swivel and hinge arrangement, by which the blades are attached to the shaft, permit them to "float" and be held close to the chilled wall of the processing cylinder by the centrifugal force from the shaft, and in this manner the heat-transfer surface is kept clean by the instantaneous removal of solidified films. The thixotropic effect of the vigorous stirring and the severe supercooling, that takes place in extracting the heat in short time through a relatively small transfer surface, keep the product in a semi-fluid condition at the outlet of the Votator tube. It is then passed through a short pipe to a so-called B-unit, a cylinder provided with one or more wire screens and sometimes with a slow agitator. In this unit the product solidifies while most of the supercooling is released under further crystallization. From the B-unit the product emerges as a soft solid, that in few seconds or minutes firms up sufficiently for handling by moulding, wrapping and packing machinery.

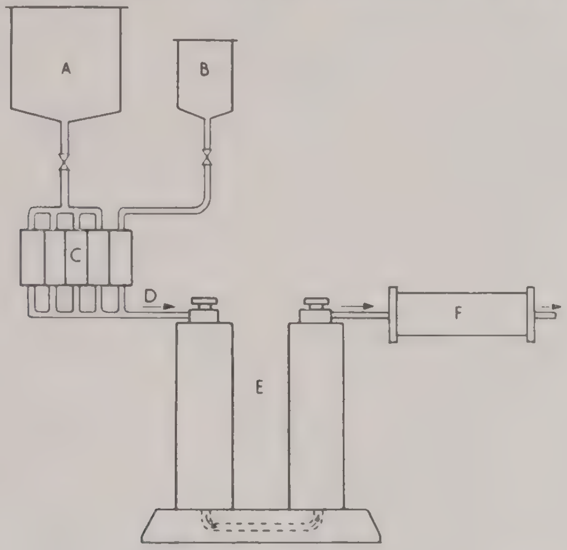

Fig. 86. Flow Diagram for Votator process.

While the main principle of the Votator process is as described, there are several arrangements of details of procedure. The preparation of fat-blends and the aqueous or milk solution follows conventional lines, but the continuous and closed system of operation requires that the various ingredients and additives are dissolved in the fat-blend or aqueous solution according to their solubility.

In one arrangement, as shown in the diagram, Fig. 86, the fat-blend *A* and the milk *B* were drawn by a proportioning pump C, roughly in the ratio 4 : 1, and passed through a common pipe *D*, where some premixing took place, to the Votator *E*, consisting of two A-units, and through a B-unit *F*, from which the finished product was transported on a short conveyor to the packing plant. The aggregate was designed for a throughput of about

2800 lbs. per hour, with a refrigerant temperature of – 15 to – 20°C and a mutator speed of about 600 r.p.m. The temperature of the semi-liquid product issuing from the A-units under the mentioned conditions was 12–14°C, varying a little with the composition of the blend; it was heavily supercooled and increased 5–8°C while passing through the B-unit, hardening up under release of supercooling. The vigorous stirring during the intensive cooling in the narrow space of the processing tube caused the final cystallization to take the form of an extremely fine network of very small micro-crystals, which with many fat-blends gave a hard consistency, when crystallization was finished. Furthermore, the combined intensive emulsification and solidification caused the aqueous phase to be dispersed in such extremely fine form, that the product resembled more a fat that an emulsion, and the flavour compounds which are principally associated with the aqueous phase were masked, giving the margarine an insipid fatty taste and flavour. In some margarines these conditions were unsuitable and although modifications of crystallization conditions, mutator speed and set-up in the B-unit could effect improvements, some manufacturers favoured a slightly different procedure, in which the milk was added in two stages.

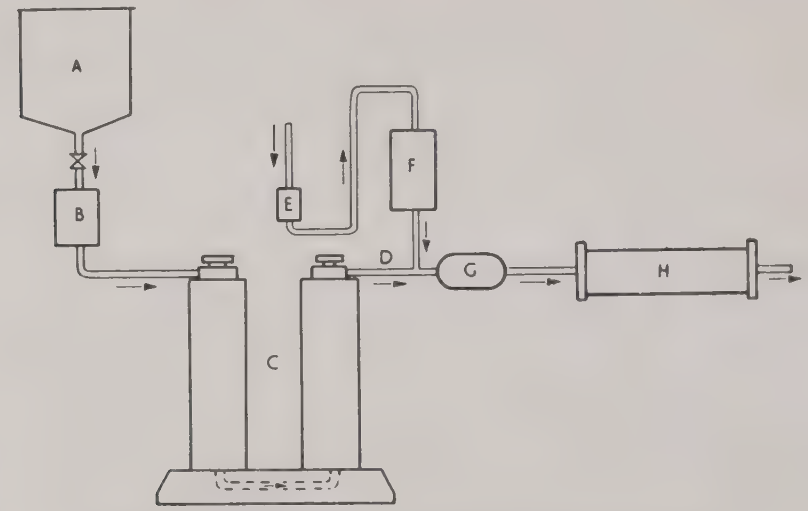

Fig. 87. Flow diagram for Votator process with blender.

Fig. 87 shows a flow-sheet for this modified process. From tank *A* the fat-blend mixed with 25 per cent of the milk is drawn by high-pressure pump *B*, and passed through the Votator A-units *C*, where emulsification and cooling take place and the reduced proportion of milk is very finely dispersed. The semi-liquid material leaves through pipe *D*, into which is injected the remaining 75 per cent of the milk under pressure from milk pump *E*. The required amount of salt is dissolved in this portion of milk, which between pump *E* and pipe *D* passes through a special cooler *F* and is chilled to – 3 to –4°C. The mixture of chilled milk and cooled emulsion from the A-units now passes to a blender *G*, provided with rod-shaped beaters, which revolve at 700 r.p.m. and disperse the salted milk in the margarine, but in a coarser distribution than the milk that has passed through the A-units. In this way a less "fatty" appearance and a more accessible flavour is claimed to be obtained. After blending in *G* the product passes to the B-unit *H*, which is provided with one or more wire screens for stabilizing and firming up, before being delivered to the packing plant.

The first margarine Votator used industrially, the so-called M.E. model, was designed for an output of about 2800 lbs. per hour and was later followed by a smaller size, the Junior Votator, for about 1500, and a larger model for 4500 lbs. per hour. The smaller model has one Votator chilling tube with refrigerant at about − 18°C, the larger has three chilling tubes and refrigerant at − 15°C. The B-unit is now usually constructed as two parallel tubes built up from sections to vary their length; the tubes are used alternately to give the margarine in them a short resting period for stabilization, and they are therefore fitted with automatic mechanically driven switch-over inlet valves in the header and with a V-piece at the outlet leading to a common extrusion tube; the extra resting in the B-unit makes the margarine more suitable for immediate treatment in automatic moulding and wrapping plant. The B-unit tubes are often jacketed for circulation of tempered water, and at the joints of the tube sections wire-mesh screens or perforated plates are

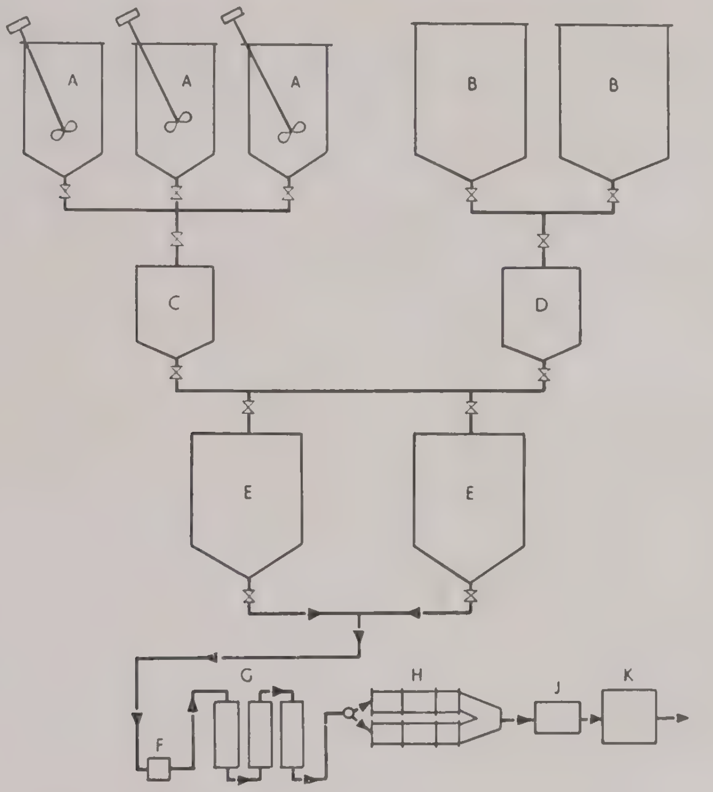

Fig. 88. Flow diagram for Votator with pre-mixers.

sometimes inserted to assist homogenization and plasticizing and to avoid channelling.

In recent years the most favoured arrangement for laying out the plant has been as shown in the flow-diagram in Fig. 88. *A* are milk treatment tanks, *B* storage and tempering tanks for the fat-blend, *C* a weighing and dissolving tank for milk and water-soluble ingredients, *D* for fat-blend and fat-soluble ingredients. *E* are emulsion pre-mixing tanks, which alternately supply a continuous flow to the 4-cylinder piston pump *F*. This pumps the material under high pressure through the 3-cylinder A-unit *G*, wherefrom it emerges with a temperature of 8–12 C, and through the 2-tube B-unit *H*. From the latter the solidified margarine passes to the moulding unit *J*, that delivers the moulded pats or prints to the wrapping unit *K*. In this arrangement a pre-mixture of all the constituents is made before pumping.

Although these various types of Votator plant found wide acceptance in the American margarine industry, many Europeans considered, that with many of their types of fat-blends the very fine close crystalline structure and dense emulsion of the Votator margarine differed too much from the types consumers preferred. Adjustment of mutator speed, temperature of refrigerant and hold-up in the B-units by altering length and screen arrangements effected some improvement, but did not meet all requirements.

As mentioned earlier, the intensive mixing during chilling and the very rapid transfer of a great amount of refrigeration for cooling and extraction of latent heat of crystallization in the very short time the product is in the A-unit leads to severe supercooling and creates conditions for formation of the solid fatty phase as a large number of extremely small micro-crystals to fairly uniform size, and when crystallization is completed, after release of supercooling and during subsequent firming up and increase in temperature in the B-unit and during storage, the small crystals form a dense network or skeleton with very narrow channels for the liquid fatty phase, thus increasing the viscosity of the latter and minimizing that internal mobility, that is a condition for plasticity and spreadability. Increasing the proportion of the liquid fatty phase by allowing time for the release of supercooling to be completed, and further increasing the temperature by tempering the product in the B-unit, combined with mechanical working by passing it through screens are methods for improving the consistency, but tempering of a very fine-crystalline substance with numerous crystallization centres and passage through screens with potential thixotropic effect may lead to reversible changes and later hardening-up.

Wilson and Oakley [170] have suggested a method for obtaining an improved consistency in Votator treated margarines by spreading the soft product, that is extruded from the B-unit at a temperature of about 15 C, through a special fan-shaped nozzle, as a flat ribbon about ¼ in. thick on a metal conveyor belt and carrying it slowly through a heating zone, where it is heated to about 24 C, depending on the fat-composition. The inventors mention a heating period of five minutes with a belt 2 ft. wide and travelling

24 ft. per min., corresponding to treating one ton per hour. Heating is effected by contacting the underside of the belt with water of 28–30°C, but other methods are also suggested. During heating, which should not involve visible melting, some of the lower melting glycerides are liquefied, and some re-orientation and re-formation of crystals may take place in spite of the short period. The belt then passes through a cooling zone in contact with cold water of about 3°C, whereby the temperature of the margarine is reduced to about 16°C in about 2 minutes, which means that the total conveying part of the belt should be 168 ft. long. The cooled product is delivered by the belt to a mechanical kneading device, such as the conventional type of worm-kneader and extruder, and is then ready for packing. The patent indicates other arrangements for warming and cooling, but the principle is the same. However, in view of the practical difficulties of heat-transfer to the ribbon of margarine, the time that is necessary to effect lasting changes in crystal formations, and the costly and spacious plant required it is doubtful if the method is of practical importance; equal or better results seem obtainable by other means.

As mentioned in the chapters on Churning and on Cooling and Crystallization, pages 163–164, the most suitable crystal formation in many fat-blends for obtaining good plasticity and spreadability is a mixture of larger and smaller micro-crystals, which will give sufficient mobility for the liquid glyceride phase at the relevant temperatures of use. Similarly, the best emulsion formation for flavour transfer on the palate is an appropriate mixture of different globule sizes of the aqueous phase, and not a uniform superfine dispersion (see page 140). The temporary lowering of the temperature during churning to below that of the average melting point of the fat-blend (see page 146), aims at the formation of micro-crystals of the higher melting glycerides as nuclei for later solidification of the margarine, so that they form, when crystallization is completed in the finished margarine, a skeleton for supporting a softer matrix of liquid and lower melting solid glycerides, the latter frequently forming overgrowths on the larger first-formed micro-crystals. This appears to be the best micro-structure of the fat for palate sensation and for rapid access to the flavour carrying aqueous phase. The use of crushed ice in the churn, as described under Churning, is a help towards this crystal formation, as is the addition in the churn of some finished margarine as "seeding" material, to which reference is made on page 150.

WILSON, OAKLEY and ROURKE have devised methods for applying similar principles to the manufacture of margarine by the Votator [171]. In one method the fat-blend is cooled and agitated to pre-crystallize a proportion of the higher melting glycerides by passing the blend through a heat-exchanger, before it is emulsified and finally cooled and solidified with the milk in the Votator. In another method a proportion of the Votator-chilled margarine is returned to and mixed with the liquid emulsion for seeding purposes, before the seeded mixture is passed to the Votator. The first method is sometimes referred to as the Pre-crystallization method, the second as Auto-precrystallization.

A diagram of the pre-crystallization method is shown in Fig. 89. (*1*) is the tank for the fat-blend from which pump (*5*) passes the blend through jacketed coolers (*7*) provided with helical stirrers; the blend is here cooled to pre-crystallization temperature, and formation of small crystal nuclei of the higher melting glycerides begins. The blend then passes through pipe (*11*) into the cylindrical pre-cystallization unit (*12*), where the extent of pre-crystallization, as controlled by the temperature in relation to the composition of the blend, is completed under agitation while the blend passes through. Agitation is effected by radial rods arranged helically on a central shaft and intermeshing with fixed radial rods on the inner wall of the cylinder. From this unit the pre-crystallized blend flows through pipe (*16*) to pump (*17*), which delivers it under Votator pressure into pipe (*21*), where the stream of pre-crystallized blend meets a suitable proportion of milk or other aqueous phase, coming from tank *2* via pipe *18* and proportioning pump (*20*). The mixture of blend and milk then enters the two-cylinder Votator A-unit (*22*), where emulsification and chilling is completed by the usual procedure, but the fatty phase consists of suitable proportions of crystals of higher melting glycerides and a matrix of supercooled lower melting fat. This supercooled emulsion, after leaving the A-unit in a semi-liquid condition, passes through pipe (*23*) to a B-unit (*24*) provided with wire screens (*25*), where crystallization is completed under slight increase in temperature as the result of release of supercooling. The margarine is now ready for packing or can be given further mechanical working if desired.

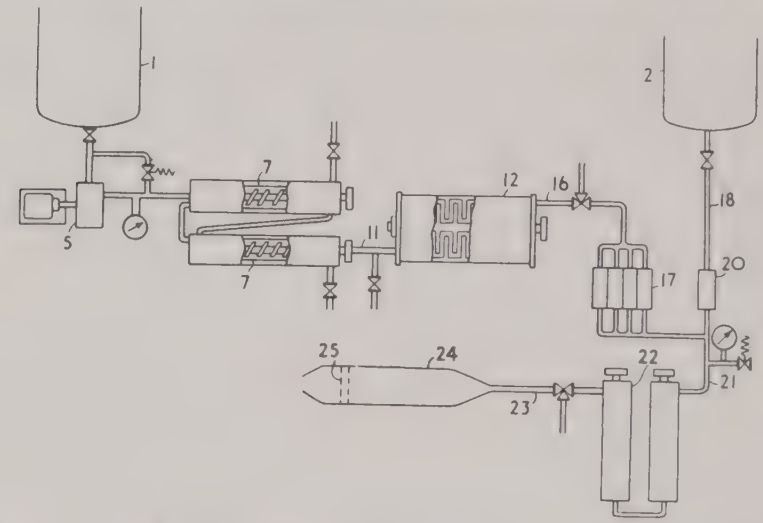

Fig. 89. Flow diagram for Votator with pre-crystallization.

As the fat-blend composition varies considerably with seasons, availability of raw materials and consumer preferences, the temperature conditions, under which the process is carried through, also vary, but with a typical European blend containing coconut oil, palm oil, hydrogenated fats and liquid oil, melted and tempered to about 42 C, pre-cooling to about 22 C might be suitable; this temperature will increase 3–4°C during pre-crystallization in the special unit, and after emulsification and chilling in the Votator the product will leave this plant at about 16°C. In some cases it has been found advantageous to pre-cool and crystallize only a proportion of the blend and bye-pass the remainder straight to the pre-crystallizing unit; for example, 75 per cent of the blend might be pre-cooled to 20°C and the remainder passed direct to the pre-crystallizer; after mixing there with the pre-cooled proportion the material might reach the Votator with a temperature of about 28°C and finally emerge from the plant at 18°C.

The auto-precrystallization method is shown in the flow diagram Fig. 90. According to this the blend from tank (*1*) and milk from tank (*2*) is pumped by proportioning pumps (*17*) and (*20*) via the common pipe (*21*) to the pre-crystallization unit (*12*) of similar construction to that described in the process above. From this unit the pre-crystallized material passes via pipe (*16*) to the Votator A-unit (*22*) for final emulsification and chilling and then via pipe (*23*) to the B-unit (*24*) with homogenizing screens (*25*). Pre-crystallization is effected by drawing from pipe (*23*) by means of pump (*5*) via *32*, *34*, *31* and *33*, a proportion of the Votator-chilled material and injecting it into the flow of liquid uncooled mixture in pipe (*21*) just prior to entering the pre-crystallizer. This chilled semi-solidified material exchanges heat with the uncooled emulsion, whereby the temperature in the pre-crystallizer is reduced to that suitable for crystallization there of the desired proportion of higher melting

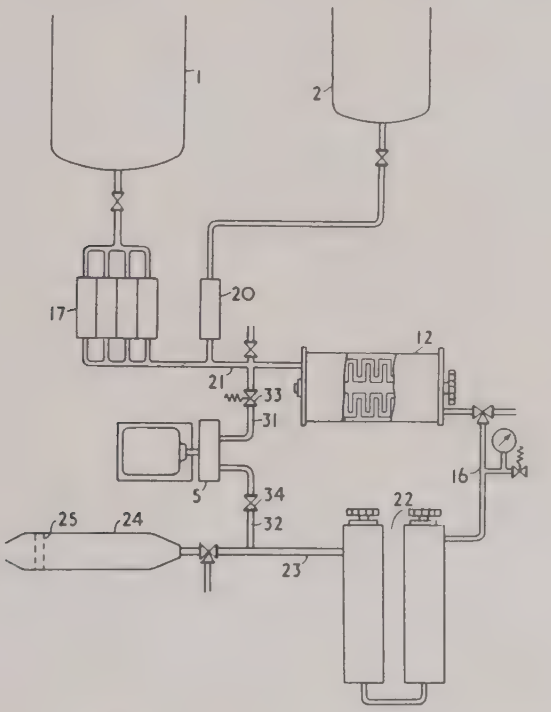

Fig. 90. Flow diagram for Votator with auto-pre-crystallization.

glycerides, while the lower-melting glycerides in the returned material are remelted. The mixture that reaches the Votator via pipe (*16*) contains therefore a proportion of the fat in the form of pre-crystallized glycerides. The proportion of chilled margarine to be returned to the pre-crystallizer depends on the composition of the blend, the degree of refrigeration in the A-unit and on the temperature of the blend in tank (*1*), and may be from 0·5–1·5 parts chilled material to 1 part unchilled blend; typical temperatures for European table margarine, made from semi-hydrogenated fat and liquid oil, are 26–27°C at the outlet from the pre-crystallizer, with a return of 0·8–0·9 parts chilled margarine to 1 part unchilled blend. With a B-unit length of 4 ft. the margarine has then a suitable consistency and structure.

As the success of Votator processing of margarine depends on careful regulation of the physical conditions, which cause crystallization to proceed at the proper rate to the desired degree, and as the material is exposed to the controlling influences only during a very short passage through the various units of the plant, reliable instrumentation, preferably automatic, adjusting flow to temperature according to the different blends, is a highly desirable feature. If the margarine finally is extruded too soft, it is difficult to handle in the packing machinery and may by slow setting and development of over-size crystals give a grainy texture and hard consistency. If it hardens up too quickly in the B-unit, temporary differences in the viscosity of the solidifying product may lead to channelling during the passage there under the high pump pressure. This tendency is minimized by keeping the cylinder surface in the B-unit tempered to reduce adhesion and by using homogenizing screens. The number and mesh of these require careful consideration, as they may lead to development of striations in the setting product, particularly if it hardens too much before passing the screens. To avoid this risk Dow and Rourke [172] suggest the use of a special construction of screens, in which the direction of flow of the material after each passage through a screen changes suddenly through a right angle, and the material is given a number of these directional changes in flow, when only partially set, for example at the inlet to the B-unit.

The Votator plant is a very compact arrangement requiring relatively small space. All parts coming in contact with the product are now made of chromium-plated stainless steel or nickel; the heat transfer cylinders are usually of pure nickel. In the 1500 lbs. per hour plant the diameter of the chilling cylinder is 4–6 in., the length 40 in.; the main drive requires a 15 hp motor, the pump for the pre-mixed liquids 2 hp and the B-unit valve motor ¼ hp. In the 4500 lbs. per hour plant the three heat transfer tubes are each of 4 in. diameter and 46 in. long; the mutator shaft is about 3¼ in. diameter; the main drive requires a 25 hp motor, the pump 5 hp and the B-unit valve motor ¼ hp. Refrigeration is by direct expanding ammonia or by circulating brine. Freon or propane are stated to be used in some installations in America, but for margarine direct expanding ammonia is the most common refrigerant. The process cylinders of the A-unit are horizontal, and the refrigerant system is in the larger plants placed in a housing under the cylinders. The liquid ammonia is pumped from a storage tank by a circulation pump to the inlet at the bottom centre of the cooling annulus and distributed via a trough along the cylinder surfaces. Automatic devices stop the circulation pump in case of mechanical failure or freeze-up.

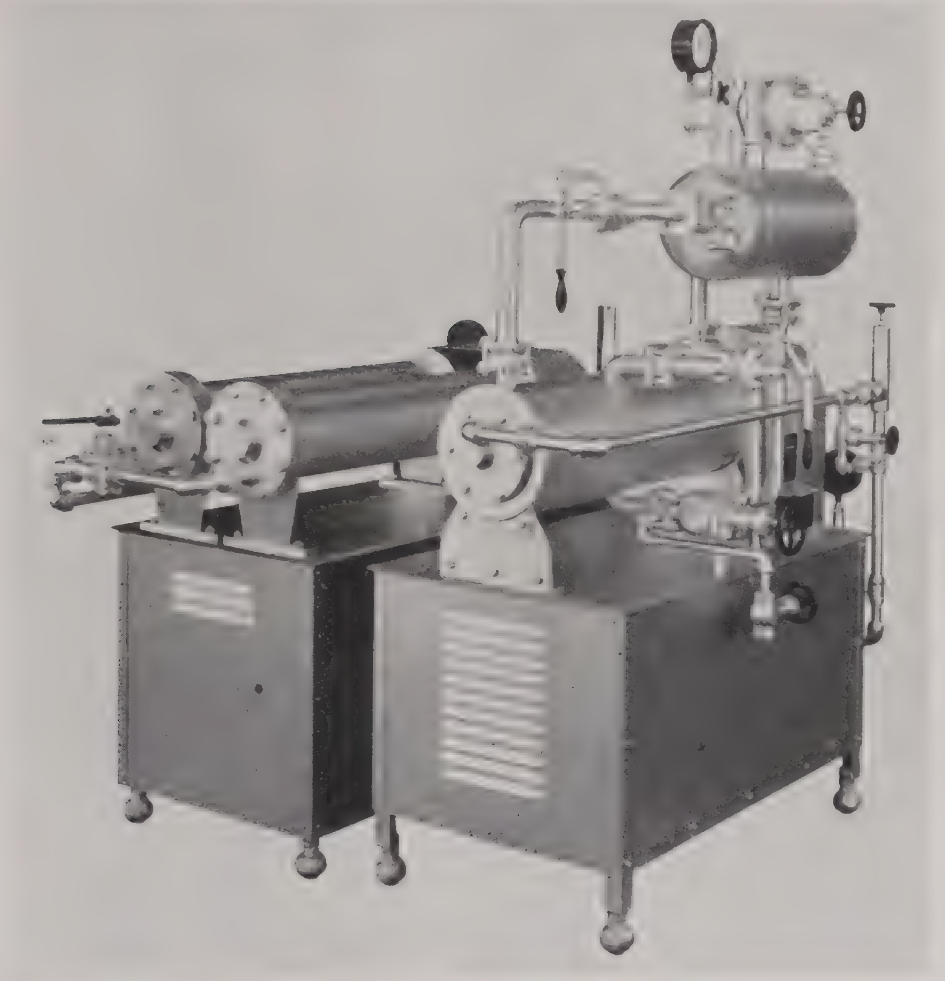

Fig. 91. Photograph of margarine Junior-Votator (Courtesy: *Girdler Corp., Louisville, U.S.A.*).

Fig. 91 shows a photograph of a Votator plant for an output of 1500 pounds per hour; on the right is the one-cylinder A-unit with refrigerant tank and regulating valves above; on the left is the two-cylinder B-unit; the latter is often arranged as two parallel passages in one cylinder. Fig. 92 is a photograph of the larger plant for 4500 lbs. per hour. It shows on the right the 3 horizontal cylinders of the A-units with drive transmission in the panel at the back and the refrigerant system in the housing underneath. The 2-cylinder B-unit with common outlet piece is shown on the left.

The Votator, and some other tubular coolers, can be used as cooling devices for margarine emulsion produced in the conventional batch emulsion churn by the pre-crystallization or seeding techniques described in the chapters on Emulsification Technique, pages 146 and 150. The number of churns and their capacities must be adjusted to give a continuous supply of emulsion to the tubular cooler. As, however, the emulsion is already established in the churn, and as an excessively fine dispersion by further intensive emulsification during passage through the cooler is not desired, the speed of agitation there is slowed down, in a Votator to 200–250 r.p.m. for example, and the temperature of the refrigerant is increased so that very little super cooling takes place; but the cooling should still be sufficiently rapid to prevent formation of too large crystal aggregates. In principle the method is similar to the pre-crystallization and auto-pre-crystallization Votator technique, but with some fat-blends and for bulk-packing the B-unit can be dispensed with, although for bulk moulding machine packing it is an advantage to homogenize the margarine by screens.

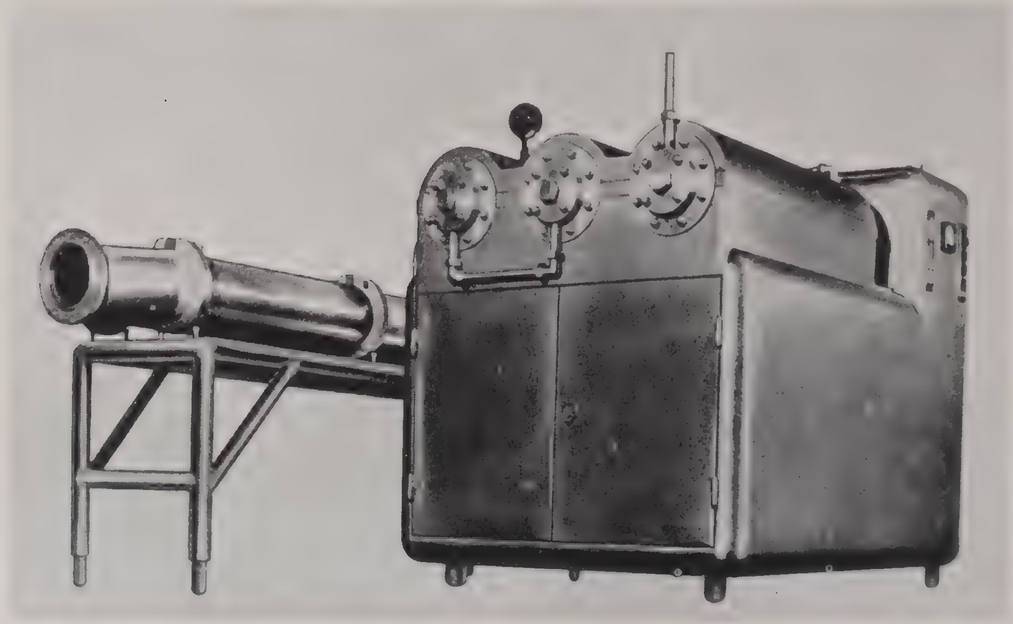

Fig. 92. Photograph of large Votator (Courtesy *Girdler Corp., Louisville, U.S.A.*).

The Margarine Kombinator, made by *Schröder and Company*, Lübeck, Germany, is a tubular cooler aggregate operating on similar principles to the Votator; it is built in sizes for hourly outputs of 500–2000 kg. The plant is illustrated in Fig. 93 and operates as follows: The two cylindrical vats in the background are pre-mixers for the emulsion which flows to the inlet funnel for the multiple-piston pump in the right foreground and is passed under high pressure through the cooling and mixing cylinders placed next to pump. In the illustration this part of the Kombinator has three cylinders, but smaller plants have only two. The supercooled, but still semi-fluid emulsion passes to the Kombinator section of the left consisting of two parallel resting tubes enclosed in a common metal cover. In these tubes, which are used alternately by means of a time-interval controlled switch-over valve, the emulsion solidifies and crystallizes while release of supercooling effects an increase in temperature. The two resting tubes join through a V-tube a common mouthpiece from which the finished margarine is extruded.

The New-Way Method.—The tubular cooler plant, built by *Bells Machinery Pty. Ltd.*, Melbourne, in accordance with the patent of J. O'CONNEL and H. KERR [173], was originally devised for converting concentrated 80 per cent cream into butter by shock-cooling and mechanical working to effect phase inversion, but has now been adapted and applied to the manufacture of margarine in several factories, particularly in Australia. The process is usually referred to as the New-Way method. The emulsion of the margarine constituents is formed in churns or other similar mixing plant and supplied continuously to a jacketed cylinder in which are fitted two parallel intermeshing helical screws on hollow shafts; the clearance between the screw planes and between these and the cylindrical wall is about $\frac{1}{4}$ in. Brine circulates through the cylinder jacket and the hollow shafts of the helical conveyors and cools the emulsion rapidly, while it is forced through this section in a thin layer in the free space between the screw surfaces and the wall. The solidifying emulsion is at the same time being thoroughly mixed and worked before being extruded through the mouthpiece as a soft semi-solid mass,

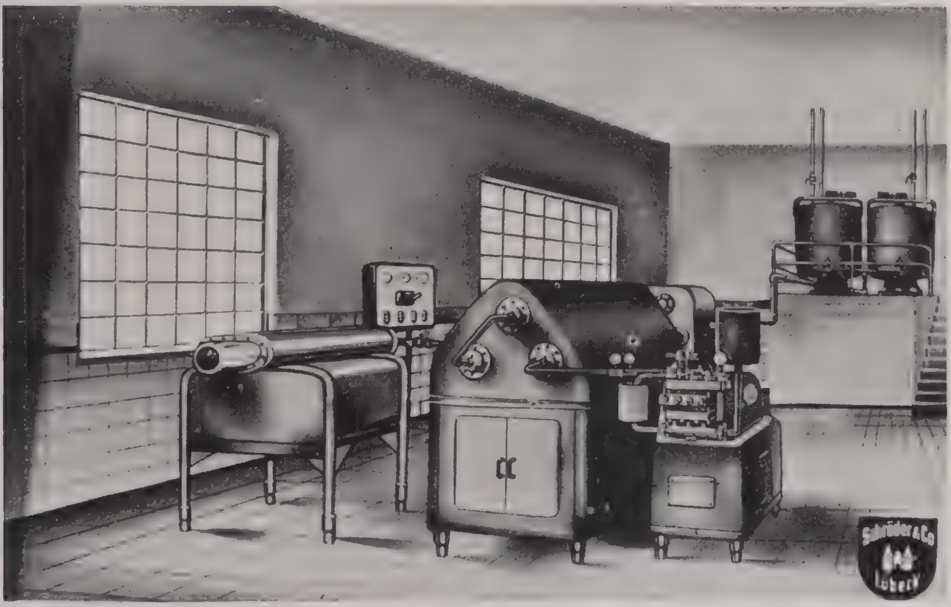

Fig. 93. Schröders margarine Kombinator
(Courtesy: *Schröder & Co., Lübeck*).

that is sufficiently mobile to run into parchment-lined moulds of the volume and shape of the dispatch packages, in which the final crystallization and solidification takes place. Sometimes a second section is attached to the cooler-extruder part to give the extruded soft material a further kneading in a blender with paddles or beaters of different constructions, before it is passed to the moulding machinery. The latter sometimes consists of a horizontal circular table with recessed lined moulds, from which the margarine is pushed out as a block by a plunger, when after one rotation of the table it is solid enough for handling. This procedure is adopted when packing in bulk packages; for small packets the margarine must be allowed to set firm, before it can be handled in the conventional wrapping machinery. Some manufacturers prefer also to give the bulk margarine 12–24 hours rest before storage for dispatch.

The Rotosan Plant of the *Atlas Company*, Copenhagen [174], is a small compact closed tubular cooler aggregate, built mainly in capacities of 100–500 kg. per hour. In this plant pre-mixing of the blend, milk and ingredients follows the conventional lines, as for example in the same Company's continuous plant with drum cooling, page 224. Fig. 94 shows a vertical section and a plan of the Rotosan cooler. The tempered pre-mixture is admitted at the float-regulated inlet funnel with filter (*1*), and a pump (*3*) with stroke-regulating device (*2*) forces it via 3-way starting valve (*4*) through the cooling and processing section (*7*) where emulsification, crystallization, plasticization and homogenization take place. The semi-solidified product leaves this section at the top and is by means of a volumetric measuring apparatus (*9*) filled into containers placed on table (*10*). The final solidification takes place in packages, as the margarine is usually at 14–16°C to ensure that the finished product sets in the right consistency. It is at that temperature frequently too soft for usual automatic packing and wrapping machinery and is therefore extruded into preformed parchment bags, supported by a tin skillet, from which the bags can be removed after the product has become firm, usually in 10–30 minutes. The Rotosan cooler is built up of a number of plate elements, consisting of alternating fixed hollow plates *A*, Fig. 95, with spiral guide channels inside for circulating the cooling medium, and rotating discs *B*, attached to and rotating with the central shaft and provided with staggered scraper knives *C* set at an angle, which serve the purpose of removing material from the cooling surface of the hollow plates and of turning over, mixing and passing on the thickening emulsion on its way through the cooler under pump pressure, thus effecting a certain amount of kneading and plasticizing. The thicker rims of the *A* elements enable them to form a cylindrical vessel, when clamped and held together by bolts *D* through registering holes in lugs on the rims. Other lugs have similar holes, which when the elements are tightened by the bolts form cylindrical inlet and outlet channels *E* for the cooling medium. This is ice-water or, for some blends, cold water not exceeding 10°C, which flows from the inlet channel spirally towards the centre in the lower part of a cooling element and towards the periphery in the upper-side spiral channels. The cooling sections can be arranged to operate countercurrent to

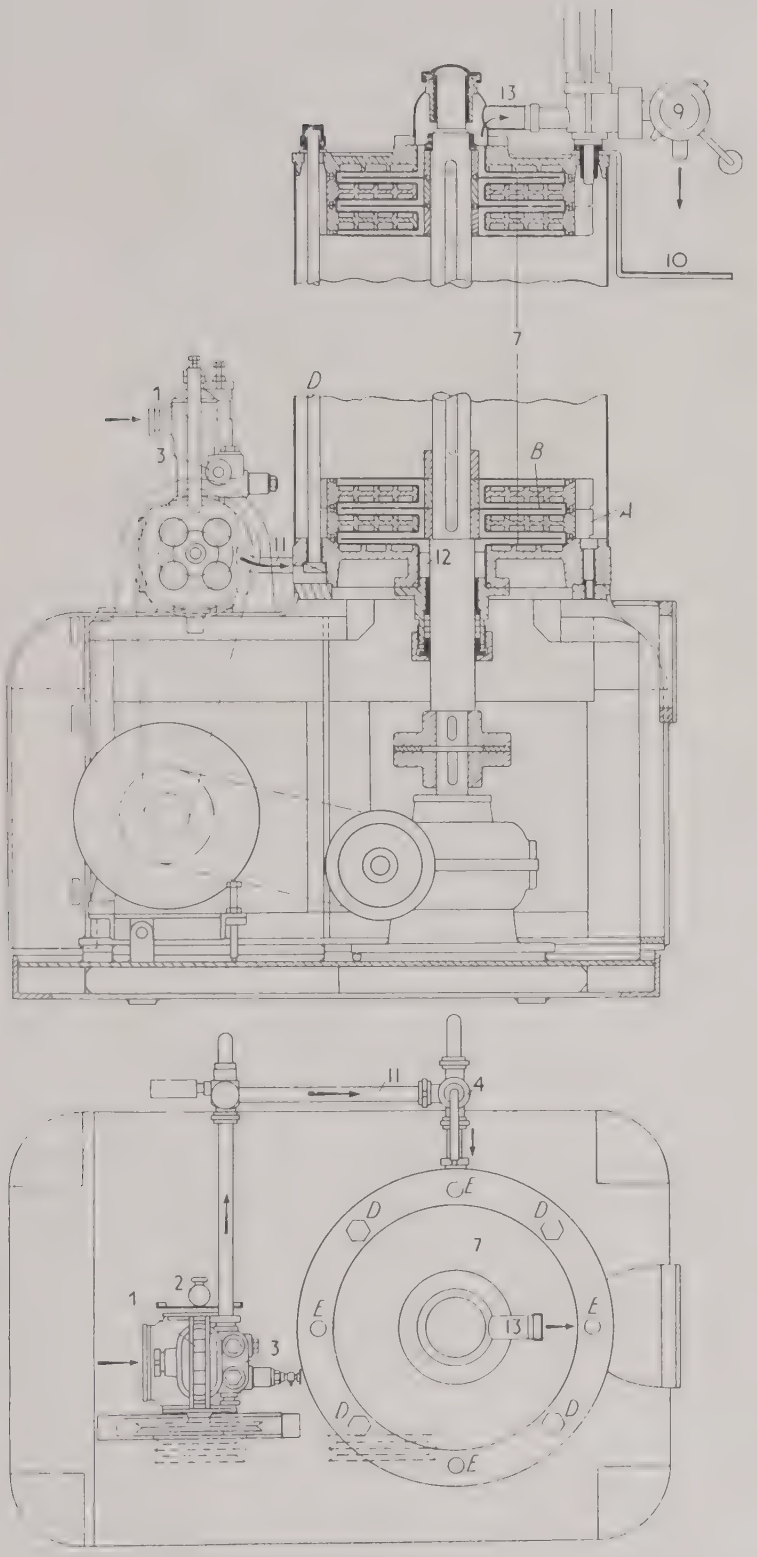
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Fig. 94. Drawing of Rotosan cooler (Courtesy: *Atlas A./S., Copenhagen*).

the flow of emulsion or concurrent, and can also be divided into subsections for use with cooling media of different temperatures, or even with slight warming up in the final elements. The emulsion enters the Rotosan cylinder through pipe (*11*) at the bottom and reaches the bushing (*12*), from which it flows between the rotating *B* plates and the cooling elements *A* outwards and inwards from chamber to chamber, and upwards until it leaves via outlet pipe (*13*). It is claimed for the Rotosan plant that it is very economical in refrigeration as cold water is the cooling medium. By avoiding very low crystallization temperatures supercooling is avoided and the crystals are therefore in the most stable form, obviating the necessity of a rest period between cooling and packing, as the passage through the plant is scheduled to take 3–4 minutes. With certain special fat-blends, requiring more severe cooling than obtainable with the Rotosan machine, this can be used as the emulsifier and pre-crystallizer, and the pre-crystallized thick liquid emulsion with a temperature a few degrees below its setting point, and with practically all the latent heat of crystallization extracted, can be finally cooled and solidified on a small cooling drum of the conventional type, which then needs only to be dimensioned for cooling the product down to 10°C. Fig. 96 shows a photograph of a small Rotosan plant built in accordance with the drawing in Fig. 94.

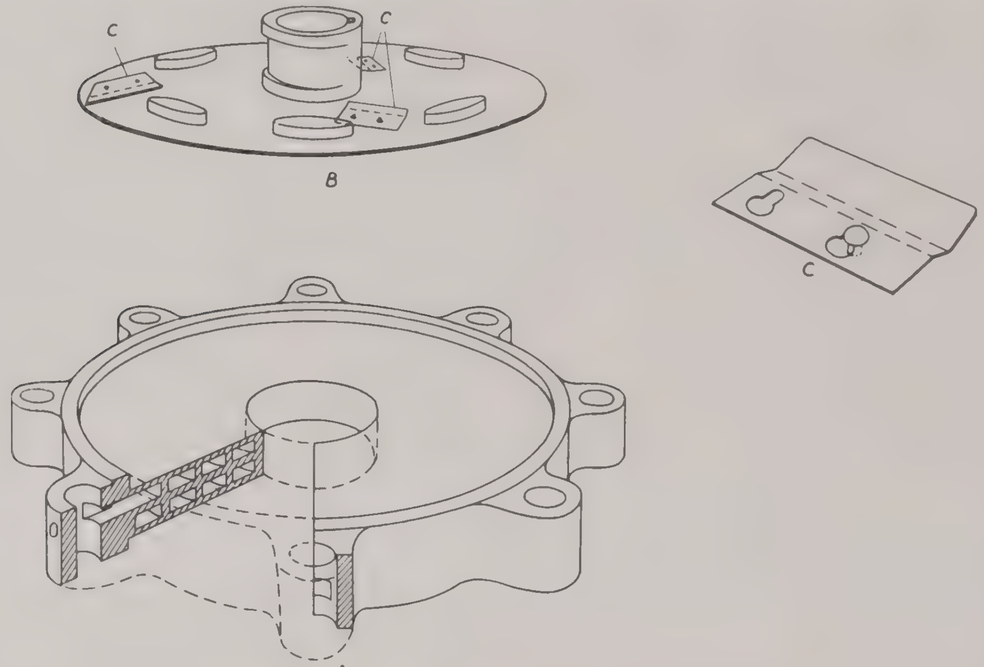

Fig. 95. Drawing of elements of Rotosan cooler
(Courtesy: *Atlas A./S., Copenhagen*).

Messrs Gerstenberg and Agger, the makers of the Diacooler and Complector plants, see page 214, now also build a tubular pressure cooler, known as the Perfector.

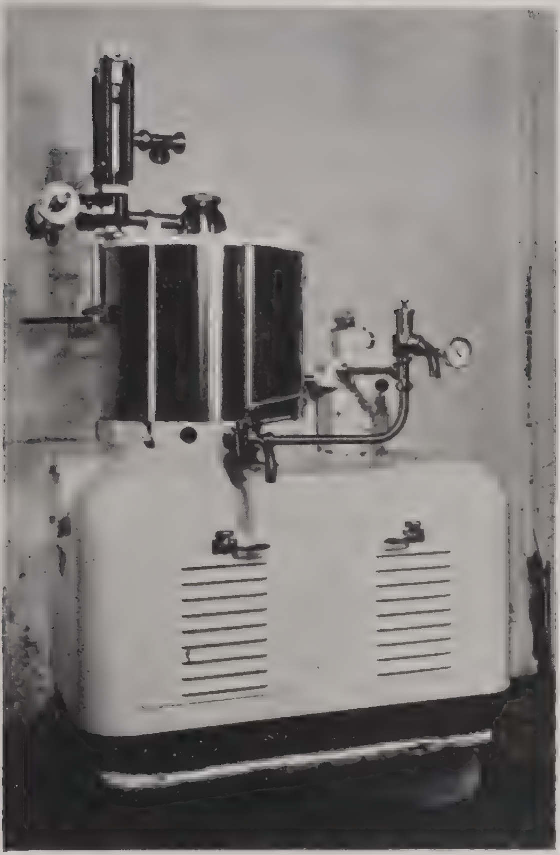

Fig. 96. (443) Photograph of small Rotosan plant (Courtesy: *Atlas A./S., Copenhagen*).

Other tubular closed coolers have been designed and several patented, but published information is mostly on cooling of shortenings and other fat-mixtures. The Rotocooler [175] resembles the cooling tube of the Votator, but the fixing and attachment of the scraper blades is slightly different.

Packing and Wrapping

1. MACHINERY

Margarine is packed in containers of many different types and shapes, sometimes in bulk, that is, in containers of such sizes that retailers can subdivide the contents to meet customers' requirements, sometimes in individually wrapped small-weight units or packets. In some countries shape and size as well as marking and labelling of them are governed by statutory regulations, in others by trade customs for dairy products or by manufacturers' or customers' preference. While at one time barrels, kegs, tubs, circular and oval containers were used as bulk packages, the tendency now is mostly to use cubical or rectangular boxes, which allow more rational and mechanical operations. Small unit packets, usually ½ lb., 1 lb. and sometimes 2 lbs., or ¼ kilo, ½ kilo and 1 kilo, have been packed in shapes of cubes, bricks, rolls, pats and prints, but the introduction of combined automatic labour-saving moulding and wrapping machinery has gradually reduced the number of shapes, so that most packets are now either cubical, which in many countries is required by statute, or rectangular. In U.S.A. such packets are usually termed prints.

When the margarine comes from the blender or from the kneading unit of the various continuous plants, it is ready for bulk packing. It is delivered to a packing table, from which it is weighed out in the required quantity and placed in the box. By means of stamping and pressing tools it is made to fit the parchment-lined box closely. Sometimes the pressing tool is provided with a design to imprint on the surface of the margarine; this is, however, not to be commended as it may interfere with the close fit of the lining paper to the surface; any airspace or air pocket between the margarine and the paper should be avoided, as such pockets easily become saturated with humidity and encourage the growth of adventitious infection from air or paper.

In many factories margarine for bulk packing is delivered to a Bulk Packing Machine which will extrude it as a bar of the desired cross-sectional area and cut this in the right length to fit the bulk container. As an example of a bulk moulding machine Fig. 97 shows one made of stainless steel; the upper part is hinged open to facilitate cleaning. The margarine is filled in through the

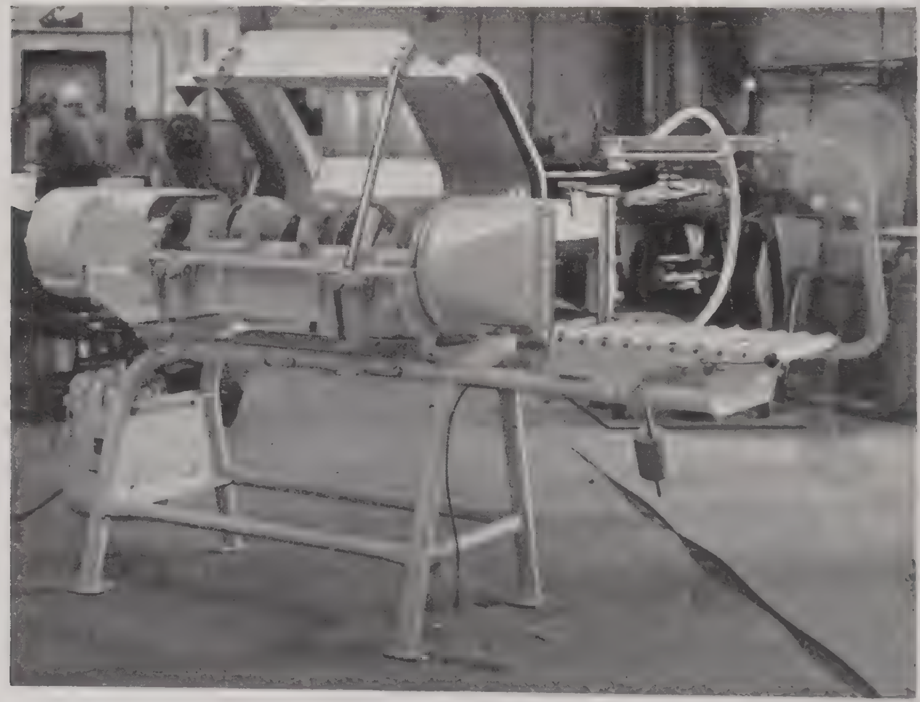

Fig. 97. Bulk moulding machine (Courtesy: *A. Johnson & Co. Ltd. London*)

rectangular opening on the top, and two worms, which are detachable and supported on the cantilever principle, extrude it under very slight pressure through the mouthpiece with adjustable orifice on to a short roller conveyor table. A foot-operated clutch controls the gear box, and a hinged frame cutting device divides the bar in suitable lengths for fitting the receptacle. This machine is driven by a 6 hp motor carried on the frame support, and it is suitable for moulding blocks of 7–56 lbs. each from margarine of varying consistency.

The tendency during the last decades has been to pack margarine for retail sales in prepacked and wrapped small units, $\frac{1}{2}$ lb. 1 lb., $\frac{1}{4}$ kilo and $\frac{1}{2}$ kilo principally, and the earlier separate moulding and wrapping machines are now largely replaced by combined automatic moulding, measuring and wrapping machines with outputs of 70–150 packets per minute or more.

In the earlier plants a moulding machine extruded through a mouthpiece of the desired cross-section a bar of margarine, which by roller or band conveyor was carried along to the wrapping unit. As the latter worked intermittently, whereas the extruder gave a continuous bar, the latter machine had to be stopped by a foot lever from time to time. When the bar reached the wrapping unit, it was cut by a knife plate in adjustable lengths and wrapped in parchment paper drawn from a stack of cut papers by vacuum "feelers" or drawn and cut from a reel.

In the modern combined moulding and wrapping machines the intermittent action of the wrapping mechanism is transmitted to the extruder section, so that synchronized with the wrapping unit it extrudes the margarine into a moulding chamber, which volumetrically measures the packet size and shape and which can be adjusted in volume to give the desired unit package with great weight accuracy. From the moulding chamber the shaped unit is then transferred in different ways to the wrapping stage, where wrapping and folding of the wrapper, supplied from stacks or by reel feed, is done automatically. Parchment of special flexibility and strength is mostly used, but sometimes laminated wrappers of different kinds, metal foil on parchment, waxed papers etc. are used. At times double wrapping or carton covers of different types are used, particularly in U.S.A.

As example of the working principle Fig. 98 shows diagrammatically the system of the machine made by the *Forgrove Machinery Company Ltd.*, Leeds [176]. The margarine is placed into a hopper and fed by intermittently rotating feed worms (*10*) into an extrusion box (*11*), which opens out into a die chamber where a plunger (*13*) moves up and down. A knife (*16*), that also moves up and down, closes the outlet from the extrusion box to the die chamber, when in the "up" position, and permits flow from the box to the die chamber, when the plunger and the knife are in the "down" position. The plunger forms the bottom of the die chamber and, when in the "down" position, is level with the bottom of the extrusion orifice, but can be slightly adjusted in stroke to allow for correction of volume and weight of the extruded block. During extrusion the top of the die chamber is covered by a sliding plate (*15*); thus the die chamber is formed by the plate, the top of the plunger and the sides of the box, in which the plunger reciprocates. When plunger and knife are in the "down" position the worms operate and extrude margarine into the die chamber thus formed, and when this is filled, the knife moves up to close the extrusion orifice; the top cover (*15*) moves to the right and thereby opens the die chamber at the top; the plunger moves up to the top level of the chamber and lifts the moulded block (*14*) of margarine free of the chamber. The sliding plate (*15*) now moves to the left and by means of the upstanding flange (*17*) pushes the block (*14*) off the plunger and on to another reciprocating lifting plunger (*18*). A wrapper (*21*) has in the meantime been drawn in from a stack or cut from a reel and placed by (*22*) above the block of margarine on plunger (*18*), which now moves up and places the block and wrapper in the gripping jaws (*19*) at the bottom of an intermittently rotating wrapping wheel (*20*), which has four pockets with jaws. Placing the block in the jaws causes the wrapper to cover three sides of it. Plunger (*18*) dwells in the "up" position till the jaws have gripped the block and wrapper, when it moves sideways to slide off the block and then down to receive the next block from plate (*15*). When plunger (*18*) has moved sideways, a folder-plate moves in from the right to press the right depending end of the wrapper against the bottom of the block in the jaws, and the wrapping wheel then turns clockwise through 90° to transfer the block to the next wrapping station. During this movement the other depending end of the wrapper is pressed against the undersurface of the block by the stationary folder plate (*23*). In the following wrapping stations, reached by further rotations through 90° of the wrapping wheel, the ends of the wrapper are

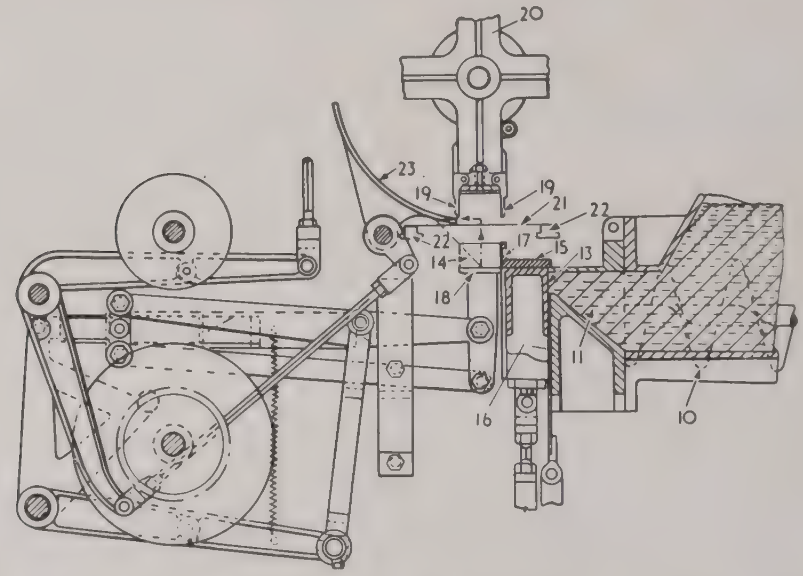

Fig. 98. Diagram of Forgrove combined moulding and wrapping machine (Courtesy: *The Forgrove Machinery Co. Ltd., Leeds*).

folded in, the block is given a slight pressure to ensure perfect shape, and the wrapped block is finally placed on a tumbler wheel, which rotates and leaves the wrapped packet with folds underneath; it is then discharged to a conveyor belt for inspection and checking. In the meantime the die chamber plunger (*13*) and the knife (*16*) have moved to the "down" position and uncovered the orifice from the extrusion box (*11*), thus permitting the die chamber to be filled again and another block formed and made ready to go through the same cycle of movements. Although the machinery and the many levers, cams and linking rods, etc., which regulate the movements and their timing, are rather complicated, the whole aggregate is quite compact in its build-up, and the mechanism is enclosed and protected against water and detergents during washing down. These machines are designed for an output of 90–100 packets per minute and require a motor of 2½ hp for driving. Weight accuracy can be adjusted during running, and a coding device for dating or otherwise marking the wrappers is usually provided to operate in conjunction with the wrapper feeding arrangement; registering of wrappers cut from a reel is effected by means of two pegs co-acting with perforations in the wrappers. The machine stops automatically when a wrapper fails to arrive at the folding position. Fig. 99 is a photograph of a Forgrove plant,

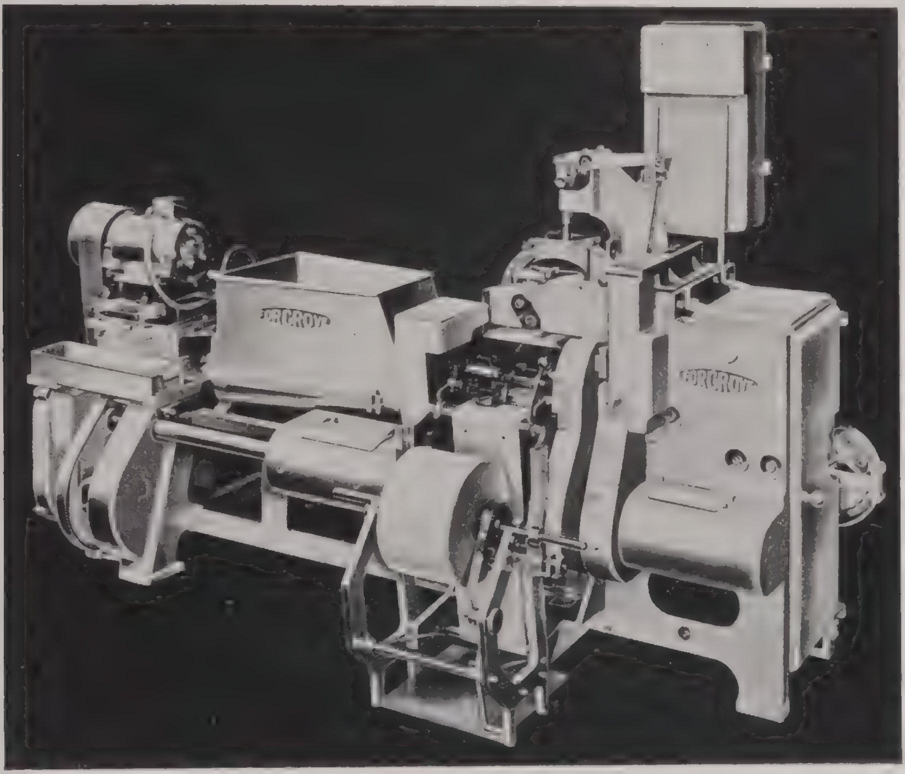

Fig. 99. Photograph of Forgrove moulding and wrapping machine (Courtesy: *The Forgrove Machinery Co., Ltd., Leeds*).

type 60B, arranged for supplying wrappers from a reel in the foreground. Registration holes in the wrapper are shown in front of the cutter mechanism. The delivery of the wrapped packets is at the opposite side.

Another combined moulding and wrapping machine, much used for margarine, is the **B.M.R. machine** of *Brecknell, Munro & Rogers, Ltd.*, Bristol, the operating principle of which is described by the diagram in Fig. 100 [177]. The margarine is dropped into a stainless steel hopper (*1*), where it is compacted by two intermittently working stainless steel worms (*2*) and pressed towards the extrusion orifice (*4*); the movement of the worms is adjustable for varying consistency of the margarine. Four moulding chambers are mounted in an intermittently revolving drum (*5*) on a horizontal axis (*65*), and when a chamber is opposite the extrusion orifice, a piston (*7*) which forms one side of the chamber moves back radially, and by its suction and by the pressure from the extrusion worms, which then are set in motion, the moulding chamber is rapidly filled with margarine (*84*). The chamber with the moulded block then moves away as the drum turns through 90°, the worms being stopped during this movement, and when the moulding wheel has turned 90° it stops and the piston in the first moulding chamber moves outward radially (*10*) and expels the block of margarine and pushes it with the wrapper (*90*) into one of the pockets (*20*, *23*, *26*, *29*) of a wrapping wheel, which operates folding, pressing and shaping in a manner similar to that described in Fig. 98. In the meantime the next moulding chamber on the periphery of the drum is in position opposite the extrusion orifice, and the cycle of operations is repeated. A main shaft is driven by a 5 hp motor, and through friction and positive clutches and a number of transmission members the movements of the various parts are synchronized and actuated intermittently. The combination of friction and positive clutches is adopted to ensure smoother actuation of the moulding wheel and its associated moving parts, and maintenance of the right phase relation during the operating cycles. This machine is designed

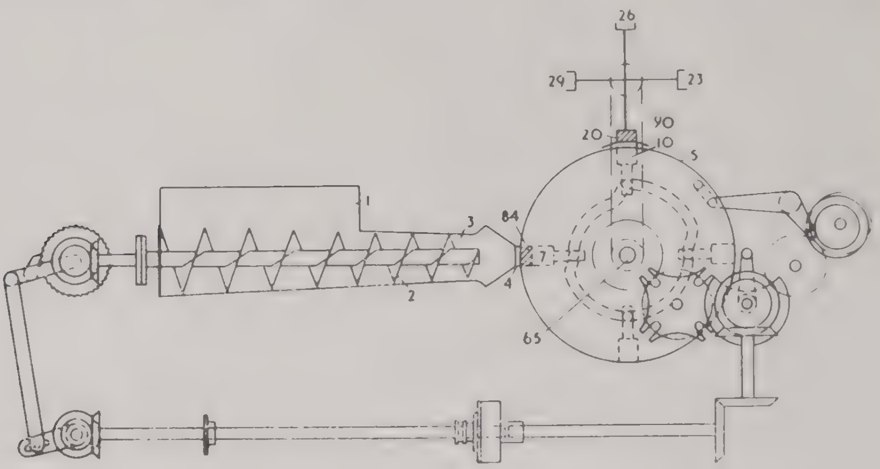

Fig. 100. Diagram of B.M.R. combined moulding and wrapping machine

to wrap up to 110 packets per minute with a high degree of accuracy of weight, and adjustments can be made during running. It is constructed for either reel feed or sheets from a stack, for which a magazine for about an hour's requirement is provided, as well as safety devices for cut-off, when wrappers fail to reach the wrapping station. The plant is fully guarded for protection during running and during washing down, but access to all parts is easily obtained.

The same firm builds also a multi-size plant, B.M.R. Mark III, designed for smaller output in factories where several unit-sizes are packed; the different parts for change in shape and volume of the margarine packet are easily exchanged. Four or more different sizes can be dealt with, and variations are not limited to length or thickness only. The construction of the machine is largely on the lines of the larger one, but the moulding chamber with piston, wrapping jaw units, folding plates, etc., have to be built in interchangeable types. This machine requires a 3 hp motor.

The Benhil Moulding and Wrapping Machine, made by *Benz & Hilgers*, Düsseldorf, was one of the first constructed for wrapping margarine. The early machine, widely adopted in the industry more than 30 years ago and wrapping 50–60 packets per minute, with separate moulding and wrapping units, has been improved repeatedly and converted into a combined moulding and wrapping aggregate. The operating principle of the modern Benhil Exact 110 plant is similar to that adopted and described under the B.M.R. section, with moulding chamber drum and wrapping wheel, but there are differences in constructional details. The machine can work either with parchment or aluminium foil as wrappers and is designed for various unit sizes from 100–500 g; an accuracy of weight of ± 0·2 per cent is guaranteed. It is equipped with the usual devices for coding and automatic stopping when wrappers fail; it is very compact and well guarded and is built for an output of 70–75 units per minute; the drive is by a 4 hp motor.

A very recent development in the Benhil range of moulding and wrapping machines is Type Rapid 220, shown in Fig. 101, the output from which is 150 units per minute, but so far it only deals with cubical packets of 250 g each.

In America the **Morpac Machinery** of the *Lynch Corporation*, Toledo, Ohio, is widely used in the margarine industry as a combined moulding and wrapping aggregate, often in conjunction with a cartoning machine for building cartons and inserting the parchment wrapped packet or print in them. In this machine the bulk margarine is delivered by stainless steel belt or otherwise into the hopper, where two worms compress and work it to the extrusion orifice and moulding box in the known manner. To ensure steady and regular feeding of the material to the worms, and thus compact delivery to the moulding box, a positive feeding unit consisting of a metal cylinder with cam-operated paddles is placed horizontally across the worm-hopper with axis at right angle to the worms; this is claimed to ensure more regular conveyance by the worms by forcing material to them and thus greater weight accuracy by the moudling box. A feature of the worms is their hollow construction, that permits circulation through them of temperature-controlled water, which also circulates through the moulding head, and aids the flow of the margarine past the metal surfaces. Very careful control of the water temperature is, however, essential to avoid discoloration of the surface layer of margarine: hence thermostatic control of the water is applied. This machine can operate either with sheet feed or reel feed of wrappers and is provided with wrapper registering and coding devices. The output when working with 1 lb. packets is about 60 per minute. Machines for wrapping ¼ lb. packets are also made, and in recent years a package system, in which four ¼ lb. packets are individually wrapped, but packed together in a 1 lb. container, has been introduced in a number of American factories in imitation of the "Butterette" pack for butter.

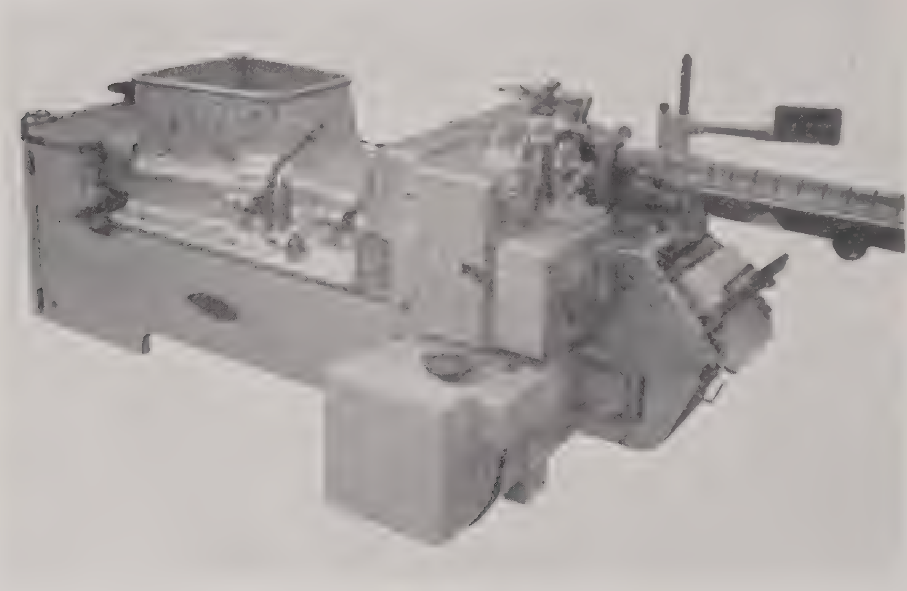

Fig. 101. Benhil Rapid 220 moulding and wrapping machine (Courtesy: *Benz & Hilger, Düsseldorf*).

Several other combined moulding and wrapping machines, constructed for butter or margarine, are on the market: they operate on principles similar to those already described, although differing in certain details, and each claims some special advantageous feature: they vary in output from 50–100 packets per minute. Some have only found local application, but among those that are used widely in margarine factories may be mentioned the Swiss plants made by *Küstner Frères*, by S.I.G., the *Schweizerische Industrie Gesellschaft* [178], and by *Etablissements Simon*, France.

The intermittent working of the moulding and wrapping of the margarine block necessitates in most machines a synchronized intermittent working of the extrusion worms and a separation of the combined moulding and wrapping machine from the kneading and finishing section of a continuous processing plant. Where it is desired to couple a wrapping aggregate direct to the outlet from a continuously discharging process plant, as for example a Votator or Complector, and arrangement of the type described by WILSON and DALZIEL [179] can be used. In this construction an extension piece is fitted to the outlet from the kneading unit, the B-unit in the Votator plant, and is provided on the top with a cylindrical overflow chamber, in which a piston can move up and down, operated by compressed air. The extension piece ends in a conical section that narrows down to a rectangular tube leading to a die chamber, as described for the Forgrove machine with reciprocating knife plate and piston. The supply of margarine from the kneading unit is continuous, but when the outlet from the rectangular tube to the die chamber is closed, the cylindrical overflow chamber from the extension piece takes up the flow of margarine, while its piston moves up to make room for it. When the knife plate again moves down to admit margarine to the die chamber, compressed air is automatically admitted to the upper side of the piston in the overflow chamber, and the overflow margarine is rapidly pressed down and into the die chamber, which fills quicker than would be the case with continuous flow from the production unit, and permits thereby an increase in the output from the wrapping unit, thus harmonizing continuous output from the production unit with intermittent moulding and wrapping, provided the total hourly output from both plants is the same. Where a production unit is large, 2–4 tons per hour, it may be necessary to employ several wrapping machines to absorb the output. It is advisable to be able to control the temperature of of the metal walls of the extension piece and overflow chamber as well as of the rectangular extrusion tube.

An important point with all these machines is the accessibility to the working parts, which come in contact with margarine and therefore require frequent and thorough cleaning. Modern machines are nearly always made with metallic surfaces, where they contact margarine, and these should be inert against margarine and its ingredients and against detergents used for cleaning. Stainless steel, nickel and chromium are the principal metals; tinned steel is now little used, and tinned copper or brass should be shunned. The surfaces should be very smooth so that blocks of margarine, when transferred from dies to other surfaces do not adhere, and it is particularly important that no margarine gets into the narrow recesses between cutter plates, pistons and boxes etc., where it may lodge during the period of working; such parts should be easily detachable and removable for frequent cleaning.

Another important point is the adjustment of packet volume during the running of the machine. Margarines vary slightly in density, according to composition, salt content, air occlusion etc., and even the same quality may show slight variations as the result of small differences during processing. As the packets are mostly sold with a guarantee of weight, and as deviations downward are often illegal and excess upwards wasteful to the manufacturer the margin of weight variation should preferably be within 0·5–1 per cent, i.e., within 1–2·5 g per ½ lb. packet. Nearly all the modern machines have means for adjustment during working, when check-weighing, mechanical or manual, shows excessive deviation. Some machines guarantee an accuracy of less than 0·5 per cent, but manufacturers often give slightly more overweight to compensate for potential loss during storage by evaporation of moisture from the surface of packets; this depends, however, principally on the fineness and stability of the emulsion and the quality of the wrapping material. Adjustment of extrusion worm travel for each impulse is also a frequent feature to compensate for variation in consistency of the margarine.

2. PACKING MATERIALS

As mentioned earlier many types of packages have been used in the past, but nowadays, except where statutory regulations demand otherwise, the package is almost universally the rectangular box, either made of wood or some fibre-board composition. Margarine for export to warm climates, or produced there, is often packed in tins.

Sometimes in tropical factories the margarine is packed in semi-liquid form direct from the churns into tin containers, where it solidifies during cool storage. In European countries tins are usually filled with the margarine in the finished state by extruding it from moulding machines through an orifice of same cross-sectional area as the tin, or slightly less to allow the air in the tin to escape; in the latter case the margarine must finally be compressed into the tin to fit tightly. The tin coating of these containers should be of high grade and free from pinholes, as contact between the moisture and salt in the margarine and the steelplating may cause development of rust spots on the surface of the product and initiate premature deterioration. Some manufacturers line the tins with parchment to minimize this risk, others just cover top and bottom surfaces of the margarine, as the seams of the joints between side and end of the tins are the most vulnerable spots for rust development owing to the leakage of air through faulty seals and damage to the tin coating during manufacture and closing of the tin.

Wooden boxes should be made from well-seasoned dry wood, free from sap, knots and resin, and free from odour that may be absorbed by the margarine. The wood should be stored in dry, dust-free rooms, as otherwise mould may develop on the surface and later gain access to the margarine. Impregnation of the wooden surface with various coating materials, such as silicate, borated casein, plastics, etc., to counter the risk of damage by micro-organisms or odours, has been proposed in various places, particularly where odourless dry wood is difficult to obtain, but the processes are relatively costly and cumbersome, and the margarine manufacturer is usually content to use as safeguard suitable selection and storage of white wood and lining of the boxes with dairy-grade parchment.

Cardboard, fibreboard and laminated board containers of different compositions have been very widely adopted in place of wooden containers for margarine in packets and for bulk margarine of weights limited to about 10–15 kg; for bulk margarine it is essential, for packet margarine desirable, that these containers are lined with parchment or similar lining material; this should be moisture repellant and free from odour. In the collapsed form these boxes are economical with storage space, but they should be stored dry. They are built up by stitching or by glueing; as adhesive it is advisable to use an inorganic material such as silicate of soda; genuine glues, dextrine and other organic adhesives carry the risk of mould growth. Fibreboard boxes are lighter than wooden boxes for holding the corresponding weight of margarine.

Lining material coming in direct contact with margarine should be of high-grade vegetable parchment, made by the sulphuric acid parchmentizing process; it should stand boiling water without disintegration. It is usually made in substance varying from 17–18 lbs. to 28–30 lbs. per ream of size 20 in. × 30 in. sheet, corresponding to about 42–72 g per square metre. It should be free from added water-extractable organic matter, such as starch, casein, sugars, etc., and deleterious metals, preservatives and free acid. Some manufacturers prefer, particularly for high-speed wrapping machines, the more flexible glycerinated quality, in which case it contains 3–5 per cent glycerine. Otherwise the total water-extractable matter should not exceed 1·5 per cent. Vegetable parchment should contain not more than 9 per cent moisture and should be stored in clean dust-free places at room temperature and 50–80 per cent humidity; if stored too dry it becomes brittle and may crack in the high-speed folding operations; if stored too damp mould growth may develop on the surface and attack the margarine subsequently; it should preferably be stored on shelves or pallets, not direct on stone floors. Too little attention is often given to suitable storage and protection of parchment lining and wrapping material, which by its direct contact with margarine can be the source of difficulty with keeping quality; it is intended to protect the margarine against box surfaces, air and dust. In addition it protects the margarine against loss of moisture from the surface and against light, which acts as a catalyst for oxidation and may bleach the colour. It should be flexible, so that it adheres closely to the surface of the margarine and eliminates all air pockets, where stagnant humid air may give rise to development of mould spots from air infection. The parchment should be practically free from microscopical pinholes, through which mositure may evaporate and cause loss of weight and a darkening of the surface film by change in the dispersion of droplets of the aqueous phase. Equally important is the evaporation loss from the point of view of cost, as it necessitates packing the units with slightly more overweight to ensure the guaranteed nett weight, when the packet is handed to the consumer. This provision against evaporation loss may easily amount to an extra 0·5–0·7 per cent loss in material.

To minimize the risk of evaporation loss and its consequences laminated wrappers are used in some factories. Sometimes the parchment sheet is laminated to metal foil, sometimes to paraffin-wax impregnated paper, but more recently various plastic sheets have been introduced for lamination. The parchment side of the wrapper should contact the margarine; waxed paper may induce oxidation, and plastics may give a flavour to the surface. Some manufacturers use double wrapping instead of laminated wrappers.

If parchment wrappers carry printed designs, which is nearly always the the case, the printing ink used should be of the fat-insoluble kind, as it might otherwise migrate through pinholes in the parchment and discolour the margarine surface. Similarly, quick drying ink should be used to avoid transfer to the unprinted side, when wrappers are bundled or reeled immediately after printing.

Special Types of Margarine

The processes and plants described in the previous chapters are those generally employed in the manufacture of the type of margarine used for table and houshold purposes, i.e., for spreading on bread, for making cakes, short pastry, pie crust, for frying and for other culinary preparations, where otherwise butter would be used. For such margarines a buttery flavour, good spreadability and a suitable plastic consistency are required. The degree of firmness of consistency varies from country to country, as does the degree of salty taste preferred. Where margarine is used for manufacturing purposes, such as in bakeries with mechanical dough-mixing and kneading machinery, or for some special food preparations, some distinct properties are often required, which necessitate some change in composition and in processing methods. Some of these margarine products are mentioned in this chapter.

Pastry Margarine.—This type is used in the preparation of flaky or "puff" pastry and in certain pie crusts. As it should in the dough ultimately form very thin coherent films in nearly parallel layers, the margarine must be of smooth texture and firm tough consistency; it should have high workability, i.e., it should stand up to heavy mechanical working and rolling under pressure into unbroken microscopical layers without crumbling. It is used by placing it in lumps or flat slabs on the prepared dough, which is folded over and rolled out flat repeatedly, so that the margarine interleaves the dough and remains as thin continuous films during working and under heat in the oven and when afterwards cooled, adhering to the dough and not running together to be absorbed in it, and acting as a shortening. These films give the lines of cleavage in the flaky pastry. This type of margarine should be rather dry and free from occluded bubbles of air; the "puff" or "lift" effect of the pastry is obtained by the expansion of moisture and baking powder in the layers of dough between the layers of fat. Contrary to the fat in Cake margarines, that in Pastry margarine does not partake in the leavening effect of the cereal part of the dough, for the making of which a small proportion of Cake margarine, lard or other shortening is used for leavening prior to the dough being rolled out with the Pastry margarine.

The composition of the fat-blend for Pastry margarine includes usually a fair proportion of high-melting fat, such as oleostearine, premier jus and hydrogenated fats melting at 44 C or higher; the animal fats are preferred because of their crystallization characteristics. With the high-melting fats oleo and lard are very suitable components, and a high proportion of liquid oil is often present. This, together with the high-melting components give this margarine its toughness and ductility, as the liquid-solid glyceride ratio does not vary over a wide range of temperatures as encountered in bakeries. Some characteristic compositions are shown on page 57.

As the melting point of Pastry margarine is usually 42–46°C, the fat-blend is heated to 55–65°C when taken into the churn, which is kept warm with a jacket temperature of 65–75 C. The aqueous phase is in most cases water, sometimes a mixture of water and unripened pasteurized milk, and it is warmed to the rather high churning temperature, 50–60 C, as no crystallization is desired during churning; hence the addition of crushed ice is not used. The aqueous phase forms only 10–12 per cent of the emulsion, and if emulsion stabilizers are used, which is rarely the case, they should be of the mildly lipophilic type; aeration of the emulsion should be avoided. The emulsion is passed to the cooling plant at churning temperature or slightly higher, 55–70 C, partly to prevent incorporation of air. Many manufacturers are strongly of the opinion, that with this type of margarine a better texture, gloss and smooth waxy finish, particularly good for layering, is obtained when ice-water of 1–2 C is used for cooling; with a water : emulsion rate of 7 : 1 immediate solidification without supercooling takes place. The ice-water drains away from the granular product with negligible loss of material, but leaves the grains in a slightly wet condition, that facilitates as a lubricant subsequent rolling and kneading treatment. In most factories, however, the warm thin emulsion is cooled on drums in thin layers and scraped off the drum as "wet" coherent sheets, which soon compact in the trucks or containers during storage and resting, while the mild supercooling from the drum is released. As the fats used in Pastry margarine are those that naturally form small crystals, this tendency can be allowed to develop without causing granularity in the cooled product, so that the structure stabilizes without heavy cooling. It is therefore customary to give this quality a long resting period before kneading, and some manufacturers use a period of up to 24 hours. This is not possible in continuous plants, but even here silos or other retarding arrangements are often used to give a "hold-up" of ½–1 hour during progress from cooling to kneading. A particularly good quality of high workability is obtained, when the margarine is given several kneading treatments with some hours' rest period between each; for example working it on duplex or multiplex rollers, followed by two or three workings on revolving tables with fluted rollers; paddle tables and particularly blenders are not suitable owing to excessive shearing effect and incorporation of air. The effect should principally be one of compression in different directions, not of grinding, and each processing should stop before thixotropic effects are noticeable.

The temperature and smoothness of the working surface should be such, that there is no adhesion between it and the margarine; hence damp wooden surfaces are preferred to metals. Tubular cooler plant has so far not been found suitable for this type of margarine, partly because of the metal construction, partly because the vigorous agitation, combined with intense cooling, induces a wrong crystal structure for this product.

Cake Margarine.—Fat is used in cakes to improve the texture and crumb and to promote the increase in volume by shortening the strands of gluten and aggregates of starch, which would in the absence of fat form a tough meshwork structure; it therefore assists the leavening of the cake in the ovens of non-fermented doughs, where rapid rising by means of gas from baking powder and water vapour is required. It also improves the tenderness and shortness of dough low in moisture, which would otherwise be too hard. Margarine is often preferred to other shortenings such as lard, suet, hydrogenated fats, etc., because of its flavour. Most table and household margarines are suitable for cake making, but to develop special qualities in cakes, particularly when made for commercial purposes on manufacturing scale, consideration is given to several points, which are of importance for the special use to which the margarine is put.

For some types of cakes, where a highly aerated dough is required, the margarine should be very plastic and over a fairly wide range of temperature and should possess high "creaming power." The fat may be looked upon as the disperse phase in an aqueous-starchy-sugary continuous phase. The dough is prepared by various procedures of mixing, which lead to incorporation of bubbles of air, or "creaming." This air is principally held in the fat, and the finer the distribution of this air and the moisture inside the margarine, the better the "creaming power." This can be assessed in various tests, for example by measuring the increase in volume when margarine and sugar, or margarine, sugar and eggs, are mixed together in creaming machinery under standardized conditions, but as both the quality of the eggs and the type and grain-size of the sugar affect the air-retaining power of the mixture, the test is only of comparable value, when closely standardized for speed of mixing, quantity of ingredients, temperature, etc., and only one variable is permitted in a test.

A fat-blend of good creaming margarines should contain an adequate proportion of high-melting glycerides, C16 C16 C16, C16 C18 C16, C16 C18′ C18, etc., either natural or obtained by hydrogenation—see page 57 for some compositions. By incorporating in the blend also a fairly high percentage of liquid oil, 25–40 per cent, or an equivalent amount of very slightly hydrogenated oil of the cottonseed, sunflower or soyabean class, adequate plasticity of the margarine is obtained together with a consistency that will support high creaming increase in volume. Some manufacturers contend that a high proportion of unsaturated fatty acid radicals in the blend increases the effectiveness of the margarine as a shortening, but this view is only justified as long as the consistency does not become excessively soft; hence liquid oils are poor shortenings, as they lack plasticity, and because of their surface tension they do not spread out in films, but incline to form globular particles. Furthermore, too high a proportion of liquid oils, if they are relatively rich in linoleic and linolenic acids (soyabean oil), may also by their proneness to oxidation, which in some cases is promoted by the presence of pro-oxidant ingredients in the dough, cause early deterioration in the cakes during storage. A Cake margarine of correct fat-blend, emulsified to give a fine dispersion of the aqueous phase and cooled to give the smooth texture of table margarines, will cream up well and hold in suspension a large volume of air intermixed with its fine dispersion of water globules. Its plasticity will ensure its fine uniform distribution in the dough, and during baking, when released from the fat, the entrapped air and the vapour bubbles from the water combine at the interface of the fat and the cereal dough to set off the aeration effect of dough moisture and gas from the baking powder. For uniform aeration of baked goods it is therefore essential to have a margarine, which ensures uniform distribution in the dough. The "creaming power" of a Cake margarine is sometimes increased by incorporating in the blend a surface-active emulsifying agent or emulsion stabilizer of the balanced type or of the mono- and diglyceride type (see page 133) and some Cake margarines may contain 5 per cent or more of this ingredient, preferably of the high-melting type.

For short tender pastry high "creaming power" in the margarine is not important, and more emphasis is given to shortening properties. The fat does not form solutions with the other constituents in the dough and does not change during baking like the proteins, starch and sugars, but it should be plastic and of suitable consistency at the temperature of dough preparation so as to form a paste with the flour and water, in which films of fat protect flour particles and protein against excessive hydration and gluten development, which is also partly reduced by the lower percentage of moisture in short paste, compared with bread, buns and other flour confectionery. Flour and margarine are therefore usually made into a paste before the water is added, thus ensuring discontinuity of the gluten meshwork and a short and tender crust when baked. If a tough and more rigid paste is required, as for example for fruit and meat pies, more water and less margarine is used to permit stronger development of the gluten with less tendency to absorb moisture from the pie-filling. In shortbread, which is very low in moisture, 4–5 per cent, the margarine and sugar is beaten into a cream and the flour added; the high proportion of fat plus sugar and the small amount of moisture cause the pronounced shortness.

The fat-blends for margarines with high "creaming power" are generally also suitable for short pastries, but emulsion stabilizers are only used in such moderate proportions as in table margarine or omitted. The absence of high-melting fats in the blend is beneficial to the tenderness and lightness of the pastry, and blends based on lard, oleo and hydrogenated fat of 32–42 C melting-point, palm oil and coconut oil, adjusted for consistency with adequate proportions of liquid oil, are widely used (see page 57).

The manufacturing processes for Cake margarines of the different types follow closely the standardized processes for table margarines. Those containing a relatively large proportion of emulsion stabilizers for high "creaming power" are not suitable for cooling by the ice-water method, as they absorb and retain tenaciously excessive moisture; nor should they be worked too much in blenders, even vacuum blenders, as the structure of the margarine gets too spongy, and they may loose plasticity and keeping quality. The dry cooling methods by drums or tubular coolers are the best. Kneading treatments must be closely adjusted in accordance with the consistency of the product to avoid a greasy texture.

An important point is the keeping quality of the margarine in the baked goods. In the preparation of the dough it becomes mixed with many other materials, flour, sugar, water, eggs, milk, baking powder of various chemicals, fruit, spices etc. Some of these have anti-oxidant, some pro-oxidant effect; water vapour in the dough at the temperature of the oven may have a hydrolytic effect on some fats, as may some of the baking powder constituents and enzymes in flour and fruit; for example, oatmeal contains a fat-splitting enzyme, as do certain crushed or chopped nuts, and bakehouse temperatures are often particularly favourable for their action. In preparations containing such enzyme products it is advisable either to destroy the enzyme or avoid margarines or fats containing coconut oil and similar fats. High iodine value oils should not be used in good Cake margarine, unless the linoleic acid content is greatly reduced by hydrogenation; but generally speaking Cake margarines show good resistance to oxidation during the shelf life of cakes and pastries, when made with a fair proportion of milk, probably because of the development of antioxidants from compounds with sulphydryl groups in the milk proteins. However, the baked products in which margarine is used as shortening ingredients are not usually made for long storage, mostly a few days only, and the question of stability therefore hardly arises. Where baked goods are required for long storage, such as biscuits, crackers, etc., shortening of the 100 per cent fat type are used.

Cream Margarine.—Where margarine is used with milk or reconstituted milk in place of genuine cream, or of butter and skim milk, in the formulation of an ice-cream mix, it should have close similarity to butter both in physical characteristics and in the flavour, which can be obtained by using fully ripened milk in its manufacture. As the salt content should be low and the use of preservative avoided, it should reach the ice-cream manufacturer soon after being made and should not be stored more than a few days before use in the mix. As fat-miscible emulsion stabilizers of the glycerol-monostearate type are often used in the manufacture of ice-cream, partly for stabilizing the mix, partly to assist creaming up and over-run, they are sometimes incorporated in the margarine, but as this would have to contain a fairly high proportion, 3–5 per cent, to be effective when dispersed in the total mix, it is often considered better to add this ingredient to the ice-cream mix separately. Where the ice-cream manufacturer prefers a neutral bland margarine, because in any case flavourings are used in the mix, it is churned with water and with sufficient emulsion stabilizer to give a good moisture dispersion in the margarine. The water should, however, be pasteurized or sterilized before churning to avoid bringing undesirable bacteria into the mix. Such a margarine keeps well.

The use of sterile water and sterile fats, i.e., fats which have been submitted to high-temperature deodorization in vacuum, is particularly important when making an unsalted margarine for use in the manufacture of synthetic cream. Special care must be taken to work under near-aseptic conditions during manufacture, packing and storage of the margarine, as the ingredients of synthetic cream, its storage, transport and mode of use is more favourable to development of micro-organisms than the frozen ice-cream.

Some manufacturers of ice-cream and synthetic cream use a suitably hydrogenated fat, or a blend of fats, in their productions, but some prefer, when not using butter, a well-flavoured margarine, as it gives in a higher degree the mellow background for added fruit and other flavours which is characteristic of good genuine cream.

Margarine Fat.—Butter is sometimes melted and rendered for separation of the fat from the water and milk solids in order to improve the keeping quality of the fat. It is mostly second-class butter that is treated in this way, and it is used principally for culinary and baking purposes under the name Clarified Butter, or in France Beurre Fondu. Canned butter for export is often made in this way. It can be of smooth or granular texture according to the method of cooling the fat after separation. The clarified fat retains much of the original flavour of butter in spite of the removal of the water-soluble flavour compounds with the water.

Margarine fat is a corresponding 100 per cent fatty product, which is an important household and bakery commodity in Germany and several Central European countries under the name of Schmelzmargarine or Margarineschmalz, and is also used in a number of Overseas markets. It is made by various procedures, but the principle is the same, namely the processing of a typical margarine fat-blend according to the standard of the district and imparting to it a rather strong flavour, either by means of fully ripened milk or artificial aroma compounds or a combination of both. As a strong aroma is favoured, less thoroughly deodorized fats, or margarine that has deteriorated slightly in flavour during storage, find at times an outlet in this way. The following examples illustrate the methods of manufacture:

300 kg cold ripened milk are run into a margarine churn and 1000 kg of molten fat-blend, consisting of 30 per cent premier jus, 30 per cent groundnut oil, 25 per cent hydrogenated whale oil 34 C m.p. and 15 per cent hydrogenated groundnut oil 33 C m.p., are added during stirring while a temperature of about 60°C is maintained. After 10 minutes' mixing the required colouring matter and 20 g butyric acid are added, and the temperature gradually lowered to obtain a thick emulsion through incipient crystallization: this is usually achieved when cooling to about 33 C, at which tempera-

ture the emulsion is run into jacketed separation tanks, where it is kept quiescent for about 3 hours to enable the fat to absorb the flavour. The jacket is then warmed up slowly and the contents of the vessel gently stirred, until the temperature is about 65°C, when the lid of the vessel is closed and the fat left still to settle in 16–20 hours, during which period the milk and most of the solids settle at the bottom, and the temperature drops to about 50°C. Froth and floating solids are skimmed off, and a little water added in a fine spray to the surface helps to clarify the fat. When this water has settled, the clear fat is decanted off through a strainer and run into wooden basins and left to crystalize and solidify as a grainy product in course of a few weeks. This fat is then of the right consistency and texture and has a pronounced buttery aroma.

In some regions a product with a "meaty" flavour is popular. For example, a fat-blend made from 50 per cent hydrogenated whale oil 36°C m.p., 20 per cent hydrogenated groundnut oil 34°C m.p., 20 per cent groundnut oil and 10 per cent meat-flavoured oil is mixed in a churn. The meat-flavoured oil is made by frying one part greaves, meat scraps, in two parts groundnut oil one hour at about 140°C, until all meat moisture is boiled off and the solids well roasted; the oil is then filtered and added to the churn. Sometimes a little sodium glutamate is added in the churn as a meat flavouring. The blend in the churn is stirred, coloured and slowly cooled till thick and grainy, and is then filled into packages for final solidification.

A product with a rather sharp cheesy flavour is finding favour in several countries. The fat-blend may, for example, consist of 10 per cent premier jus, 50 per cent hydrogenated fat of 35°C m.p., 25 per cent coconut oil and 15 per cent groundnut oil. As aroma is used 2 g diacetyl and 10 g butyric acid per 100 kg fat. In addition, a cheese aroma is prepared by dissolving a sharp-tasting local cheese to the extent of 7 per cent in the warm coconut oil before the latter is added to the blend. The cheese is ground and heated in the coconut oil until the water is boiled off, when the mixture is strained and then blended with the other fats. Colour is then added to give the desired tint and the blend is run into crystallization basins placed in a room of 8-10°C and left to complete soldification 4–5 days, before packed for dispatch.

The described products have all a more or less granular texture. Where smooth texture is required the solidified material can be milled and kneaded on porcelain or granite smoothing and plasticizing rollers of the type described on page 196, or the blend, when cooled in the churn to form microscopical crystallization centres, can be solidified on cooling drums or in tubular coolers without aeration. If cooled on drums it must be consolidated on rollers or, after a resting period, in the compression worm extruders.

As mentioned earlier, these products have good keeping quality. Those made with high proportions of skim milk for aromatizing purposes seem to benefit from the natural antioxidants in milk, even after all the milk constituents have been removed. Those made directly from the fats are practically sterile and free from moisture. The "Schmelzmargarines" are coloured in imitation of butterfat. White products, smooth or granular, aerated or non-aerated, are also made and are usually bland and flavourless; they serve similar purposes as those described, but are of the shortening or compound lard type.

Vanaspati, Indian Margarine.—Vanaspati is the official Indian designation of a 100 per cent vegetable fatty product, made as a substitute for the Indian type of indigenous butter, Ghee. Climatic conditions in India, Pakistan and several other Middle-Eastern or Eastern warm countries make butter, produced under primitive native circumstances, a too perishable substance to be of practical value; the butterfat is therefore separated from the aqueous part, and the clarified solidified fat is in India called Ghee, in Arabian and surrounding countries Semneh or Samnah.

As raw material serves the milk from cows, buffalos and, to a smaller extent, sheep and goats. By the old method, which is still the principal one, the milk in its raw condition or, as is often the case, after boiling and cooling is placed in pans or earthenware jars and kept at a temperature of 20–30°C or slightly higher, after a small proportion, 2–3 per cent, of acid curd from the previous production has been added as seeding material for development of acidity by lactic acid bacteria; without this seeding or starting material other types of organisms might predominate and cause putrefactive and harmful changes in the milk. The temperature, at which the milk is kept, is usually the local one in rooms and farms, but in cold weather the vessels with the milk are placed near ovens or fireplaces. According to the temperature the milk develops 1–1·2 per cent acidity as lactic acid and forms a smooth mild acid-tasting curd. This is often used as such under the name Dahi and is a popular food or food ingredient. If required for ghee the the curdled milk is churned in household or larger churns, sometimes in glass vessels, to produce butter. At times several days' production of milk, nearly always morning and evening milk, are bulked together to get sufficient for a churning. With good quality milk, carefully boiled and cooled, and with fairly pure bacterial cultures for acidity development, the fresh butter has a pleasant flavour and low acidity, but under modest farmhouse conditions the flavour is often strong and sharp and some splitting or hydrolysis of the butterfat is common. When sufficient butter, often the yield from several days, has been accumulated to give a household or trade measure of ghee, it is converted into ghee, mostly by the boiling process, sometimes by the decantation process. The accumulation and storage of the butter under often rather unsuitable conditions contribute to the development of the sharp, to Western palates somewhat rancid flavour of ghee.

The conversion of butter into ghee by the boiling process consists in melting it in pans or vessels and heating it to 100–110°C, until all water is boiled away, when crackling sounds stop and the milk curd gets a yellow to brown colour. In some places heating is continued till the curd blackens and chars, but this imparts an undesirable harsh and cooked taste to the fat and tends to destroy its yellow colour. A maximum temperature of 120–130°C is best.

The clear fat is then strained to eliminate curd particles and cooled to about 30-40 C, when it is run into tins or other containers and allowed to solidify slowly. The slow setting and crystallization produces a grainy texture which is usually demanded, the size of the grains being determined by the temperature, at which the fat is left to grain, and by the rate of cooling. Buffalo ghee should grain at slightly higher temperature than cow ghee.

In the decantation method the butter is heated to nearly 100 C, but no water is boiled away; together with the curd particles it settles at the bottom of the vessel, and the clear butterfat, ghee, is decanted off, cooled and run into storage containers for graining and solidification. Ghee made by the boiling process is slightly higher in acidity than when made by decantation; on the other hand, it is less prone to oxidation as indicated by the peroxide test; this is due to antioxidants from the hydrolysis of hot curd particles in the presence of acid being absorbed in the fat; probably some aroma compounds are also being formed in this manner, and many consumers prefer the more aromatic and better keeping product from the boiling process. These indigenous processes are known as the *Desi* processes.

More modern, but not so widely used, is the "creaming" method, in which cream is produced centrifugally from fresh pasteurized milk and without souring made into butter; this can then be converted into ghee by the described methods, but while this kind of ghee to Western standards gives a cleaner and milder product, it is in India considered rather flat and insipid in taste and not prized as highly as the flavoured ghee from soured milk and stored butter.

Cow ghee is, when fresh, yellow from the carotene content in the fat and has a melting point of 32–38 C; buffalo ghee is nearly white, harder of grain and melts at 36–42°C. Mixtures of them are common.

Owing to the relatively high price and increasing shortage of ghee much adulteration with different fats took place, until about 30 years ago the manufacture of a modern substitute commenced on industrial scale. This product, which stands in relation to ghee as does margarine to butter in other countries, must for ritual reasons be made from vegetable fats and oils, and it was the development of the hydrogenation process for vegetable oils, that enabled manufacturers to produce a substitute fully equivalent, physically and nutritionally, to ghee, and of regular standardized quality. This vegetable product was by decree termed Vanaspati. It has become of great economic and nutritional importance in India and Pakistan; while the production rapidly grew since its introduction to about 90,000 tons per annum just before the war, it has since grown considerably and is now of the order of 250,000 tons per annum or more.

While the earlier products were made from various hydrogenated oils or mixtures of these with coconut oil and other vegetable fats and oils, quality considerations soon led to the almost universal use of hydrogenated vegetable oils of different kinds, and the introduction in 1947 of a Government specification for Vanaspati further emphasized this composition and laid down limits for melting point, 31–37°C, butyro-refractometer reading, not less than 48 at 40°C, unsaponifiable matter, not to exceed 1·5 per cent, free fatty acids, not to exceed 0·25 per cent as oleic, moisture not to exceed 0·25 per cent, diacetyl, not to exceed 6 p.p.m., and required that the product contained no harmful colouring or flavouring and was clear when melted. Furthermore it should contain 5 per cent of refined or refined hydrogenated sesame oil, to give a defined red colour in the Baudouin test, when one part Vanaspati is mixed with four parts refined groundnut oil. It should also contain 300 i.u. vitamin A (synthetic) per ounce.

In Pakistan the regulations are slightly different in some details. Vanaspati should be free from animal fat and fish oils and should contain not less than 50 per cent hydrogenated vegetable oil. Regulations as to melting point, refractometer reading, unsaponifiable matter, free fatty acids, moisture and addition of sesame oil are as in India. Harmless colours and flavours are allowed, but diacetyl should not exceed 6 p.p.m. There are no provisions as to vitamin content.

The manufacturing process is comparatively simple, but less so is the problem of giving the finished product the desired grainy structure and flavour, which both are far from standardized for the different districts. Some Vanaspati factories have their own hydrogenation plant and refinery, others draw the supply of hydrogenated fats from outside. In India, the most frequent and favoured raw material is hydrogenated groundnut oil; in Pakistan, where the production of cottonseed oil predominates, hydrogenated cottonseed oil is principally used. Hydrogenated rapeseed and mustardseed oils are also sometimes used, but their refining and hydrogenation at times entails dfficulties, because of unsuitable storage conditions for the seed. Hydrogenated sesame oil is an excellent material, but only limited supplies are available beyond what is required as indicator substance in India. Linseed oil has now and then been hydrogenated for Vanaspati, but it does not give a product of satisfactory keeping quality, particularly now when the upper limit to melting point is 37°C, which does not permit sufficient hydrogenation of this oil to reduce adequately the compounds of higher unsaturation.

The various oils can either be hydrogenated direct to give the desired melting point of 36–37°C and, with suitable selection of catalyst and hydrogenation conditions, the right proportion of iso-oleic acids and saturated acids to promote the correct grain formation on solidification. Or hydrogenated fats of different characteristics, resulting from different conditions of hydrogenation, can be mixed together to ensure the desired proportions of solid and liquid glycerides in the final product. After hydrogenation and deodorization the fat-blend is mixed in a churn or jacketed vessel, provided with agitator and constructed of tinned or stainless steel, with colouring and flavouring substances and adjusted for the temperature, at which it is run into the dispatch containers, where crystallization and solidification take place. In some plants the liquid mixture from the blending vessel is passed over a cooling drum or through a tubular cooler in order to reach more rapidly the temperature, when microscopical crystal centres begin to form before the product is stored in the containers for final crystallization and solidification. The filling temperature varies according to the size of the container, the storage temperatures and the grain required and may be from 40 to 60°C, but if cooling before filling is used, it should be regulated so as to avoid formation of large visible aggregates of solidified fat.

Vanaspati is usually packed in tinplate containers of different sizes, some proprietary brands in small containers of 1–5 pounds, bulk supplies in tin boxes up to 40 lbs. Crystallization and solidification take place in the containers in warehouses, and to ensure that the right grain size is developed, the temperature during warehouse storage, as well as the filling temperature, must be related to the size of the container. Small containers cool more quickly than large ones and a higher filling temperature is therefore used, 55–60°C; large containers of 20–40 lbs. may be filled at 45–50°C. Too rapid cooling leads to grains being too small, hence small containers may have to be stored for a period in rooms where no air circulation takes place, so as to avoid too rapid cooling of the material at the container surface relative to cooling of the inside. After storage for a day, air at 30–32°C may be circulated through the room, and later again cooler air. With larger containers air circulation may be necessary from the beginning and also cooling of the air by refrigeration towards the end of storage for crystallization, as a temperature of 25–28°C is required which may be difficult to attain without special air-cooling. Containers should be stacked in the crystallization room in open formation, so that air can penetrate the stacks and contact the containers. The rate of air circulation and adjustment of its temperature is regulated by the circumstances ruling at the time as to pre-cooling, filling temperature, size of containers, quantity stored, outside temperature, etc. The important point is, that cooling down to the melting point of the fat should be slow, after that point more rapid. All these factors influence graining.

Colouring matter, either natural or synthetic, is added to give a pale yellow colour, sometimes with a slight greenish cast. Some regions prefer, however, a nearly white product.

Most Vanaspati's are flavoured to imitate the strong, sharp flavour of ghee made by the desi- or indigenous process. As described above, this aroma is probably the result of some degradation and hydrolysis of the butterfat, of changes in the curd during boiling off of water and further heating of protein, caramelization of milk sugar, and of interaction of glycerides and lactic acid as well as of hydrolysis of casein by lactic acid; there may also be some internal change in the fatty acids in the direction of oxy-fatty acids, which with the dehydrated lactic acid may form lactones. The subject of aroma formation in ghee has been studied by RAMASWAMY and BANERJEE [180], but much still remains to be elucidated. Manufacturers have adopted various methods for imparting a similar aroma to Vanaspati. Some prefer the simple method of adding in the mixing vessel some synthetic flavours imitating more or less closely those of natural ghee; among those may be mentioned ethyl butyrate, butyric acid, diacetyl and acetoin, which are constituents in genuine butter flavour, pineapple essence, amyl acetate, etc. Other manufacturers prepare an aroma concentrate by heating the pressed wet acid curd from skim milk or reconstituted skim milk, acidified with dahi curd or bacterial cultures to an acidity of about 1 per cent lactic acid in the whey, in some of the Vanaspati fat-blend, until the moisture is evaporated, and then continuing the heating to 115–120 C, when the curd turns brown and grainy. The fat is filtered from the dark curd and added to the Vanaspati blend. To produce an aroma concentrate about 1 part of pressed curd is used to 9 parts of blend, and 2–5 per cent of the aroma concentrate is used in the final product, accord-to taste. Some manufacturers introduce some of the strong flavour of natural ghee by adding to the heated curd in the blend some strongly tasting cheese, the flavour of which is absorbed in the fat, and some manufacturers use a combination of the curd and the chemical flavouring method. As standards of flavour vary from place to place, no universal preferable method can be laid down, and some are guarded as alleged factory secrets. A number of commercial flavour preparations are on the market, based on synthetic chemicals of the types, which by analysis have been found to be present in ghee, plus various conjectural compounds. It would appear logical to base the flavouring on heated curd products, which also yield useful antioxidants, plus the known components of natural butter flavour, such as diacetyl, acetoin, acetic, formic and propionic acids, together with butyric acid to match the hydrolized butterfat in ghee, but quantitatively all these compounds should only be present at the level of some parts per million.

With melting point not exceeding 37°C, and being mostly packed in tinplate containers, the product is often exposed to physical changes, because of unsuitable storage in the warm climates of ghee-consuming countries, but once the Vanaspati has been made of the right crystalline grain formation, it will revert to a similar texture after considerable temperature fluctuations owing to the presence of the right number of crystal nuclei in the fat.

As margarine in Western countries has been the subject of many thorough studies as to its nutritive value compared with butter, so has Vanaspati been closely studied both in India and in other countries to ascertain whether it can fully replace ghee in the Indian diets. Although the general knowledge of fat-nutrition can largely be applied to ghee and Vanaspati, it has usually been based on fat as an ingredient in diets of the Western type. The governments of India and Pakistan have during the last 12–15 years become very nutrition-conscious owing to widespread malnutrition in these countries, and several investigations of the value of Vanaspati and other Indian fats and oils in local diets have been undertaken [181]. These studies have shown that, if made according to the official specification, Vanaspati is a high-grade fatty food and from a nutritional standpoint fully equivalent or superior to many of the edible fats consumed in India and Pakistan.

Ghee itself varies in nutritive value as a result of varying conditions of production, which sometimes cause high acidity in the fat and partial or complete destruction of the vitamin content: it could be improved in quality by developments in animal husbandry, but the amount produced is far short of the needs. There is a general shortage of good fats in the Indian diet and the growing industry of Vanaspati manufacture is a valuable contribution to improved nutrition in India and Pakistan.

IV. STORAGE AND PRESERVATION OF MARGARINE

Warehousing.—After being packed, the margarine should be warehoused in cool airy rooms, free from excessive humidity and separated from process and packing rooms. Wooden packages can usually be stacked in higher piles than fibreboard containers, the height depending in each case on the strength of the lower boxes to carry the weight of those superimposed. They should not be placed direct on the floor, but on racks or pallets to permit circulation of air under the pile; some fairly open formation of storage piles is advisable for the same reason. It is a great advantage to be able to maintain cool conditions in warehouses at all seasons, but prolonged storage at very low temperatures is unnecessary and may be harmful to texture and consistency of many compositions. When the margarine is packed it has usually a temperature of 13–18 C, according to climate and season. A suitable temperature in a factory warehouse is 4–5 C, and the margarine ought to be stored a couple of days at that temperature, particularly in the milder season, before being dispatched from the factory.

Preservation.—Margarine, like butter and other fatty foods, deteriorates in course of time, but the onset of deterioration can be considerably retarded by suitable conditions of storage, composition and process control. In countries with a well-organized distribution system, including transport, retailer and consumer contact and stock turn-over, margarine ought to be consumed within three weeks of manufacture, when the flavour is at its best, but in practice it is often found that retail stores and consumers are too scattered to ensure such rapid turn-over, and that margarine therefore should keep in saleable condition for 5–6 weeks, and in exceptional circumstances and for export considerably longer.

The deterioration of margarine is usually described by the terms "rancidity" and "staleness" which, however, cover various faults. "Hydrolytic rancidity," which is shown by gradually increasing hydrolysis of the fat and development of free fatty acids, gives a sharp soapy flavour to the margarine. "Oxidative rancidity" is characterized by development of peroxides and more permanent oxidation product in the fat and gives the flavour usually described as tallowy. A "sour" or "yeasty" flavour may develop as the result of infection by various undesirable micro-organisms and their fermentation processes in the margarine serum, or a "dirty" or "earthy" stale flavour may be traced to infection of the serum with organisms from water.

Hydrolytic rancidity, which is principally caused by enzymic activity of micro-organisms, is referred to on page 122 and is mostly encountered in fats of the coconut oil group, containing fatty acid radicals of the relatively low-molecular type, which give fatty acids with a sharp soapy taste. The lipolytic or fat-splitting enzymes of some organisms are accompanied by enzymes of the dehydrogenase type, which do not require atmospheric oxygen and can lead to the formation of strongly odorous methyl-ketones, the cause of what is sometimes termed "perfume rancidity." Various moulds have strong fat-splitting effect in the presence of moisture and air, for example *penicillium glaucum* and certain other penicillia, *aspergillus niger*, *oidium lactis*, *cladosporium butyri*, etc. Several yeasts, particularly some of the *torulaceae*, as well as a number of bacteria have strong lipolytic enzymes; some of these bacteria have rather strong salt tolerance. The lactic acid bacteria used in the preparation of the milk have no lipolytic effect and often help to suppress the harmful organisms, which gain access to the margarine, either as survivors of pasteurization or, more frequently, as infections from air, plant and packing materials.

Oxidation rancidity, also discussed under antioxidants (page 121) can be caused by beta-oxidation of saturated fatty acids and by oxidation of unsaturated fatty acids, particularly di- and triethenoid acids; it is partly an enzymic reaction, due to lipoxidase, partly an autoxidation, the enzymes responsible for beta-oxidation being peroxidase and catalase. Oxidation also plays a part in the above-mentioned methyl-ketone formation, where the enzymes of the dehydrogenase type are active.

The sour and yeasty flavour is caused by yeasts of the *saccharomyces* and *torula* types developing in the milk serum globules in the margarines as the result of infections.

The stale or earthy flavour is usually caused by bacterial infection through water being left on idle plant after insufficient cleaning, or through the use of non-sterilized water as addition to the aqueous phase. It can also be caused by the use of ice made from infected water or on insufficiently cleaned ice-making plant.

All these types of deterioration are promoted by higher temperatures and by favourable pH values in the serum; to meet the demand for a good keeping quality consideration must therefore be given to storage, composition, processing, plant and materials.

Storage.—It has already been mentioned that margarine after packing should be warehoused in cool rooms for a time to reduce the processing temperature to one more suitable for preserving the quality. A suitable warehouse and storage temperature for margarine that may be expected to be consumed within 5–6 weeks is, as stated, 4–5°C. Where longer storage is necessary, 1–2 C is an advantage, but the texture and flavour may suffer slightly. Storage at temperatures below freezing point has no advantage. During transport it may in many countries be difficult to ensure the same low temperatures, hence the importance of getting the margarine cooled down before dispatched, but in dealers stores and warehouses it should be kept in cool, dry, airy places and away from strongly smelling goods. During cold weather warehouses may not require extra cooling.

Composition.—Most refined oils and fats are sterile, when used in margarine, and practically neutral, i.e., they contain less than 0·1 per cent free fatty acids. Animal fats such as oleo, lard, premier jus, etc., used in the unrefined state because they have been sufficiently well prepared, may be slightly higher in acidity, 0·3–0·4 per cent, but their type of free fatty acids does not materially affect the taste in such small proportions. If they have been suitably handled, packed and stored they are also mostly sterile. When the fat-blend is emulsified with milk or other aqueous materials, there is a tendency for the acidity of the fatty phase to increase slightly, and it may in course of 3–4 weeks be 0·14–0·25 per cent, calculated as oleic acid, unless some enzymic or bacterial hydrolytic activity is caused by faulty processing and control. Modern factories with well controlled processes are rarely troubled by hydrolytic rancidity. There is, however, a slow oxidation of the fatty matter as the margarine gets older, particularly when the fat-blend contains oils with glycerides of the linoleic and linolenic acid type; this oxidation can be measured by the increase in peroxide value, before it can be detected organoleptically. As it is promoted by higher temperatures, excessive exposure to air and light during manufacture and incorporation of air during churning and kneading, as well as by contact with certain metals, such as copper and iron, during processing, it can be considerably reduced by suitable process control and storage. It has in recent years been shown that too high serum acidity tends to promote oxidative rancidity in fat-blends containing the more unsaturated glycerides; many manufacturers therefore partly neutralize the serum, see pages 94 and 106. Another step towards retarding oxidation is to incorporate in the fat-blend an antioxidant, which is now permitted in some countries (see page 124), but the efficacy of this is complicated by many conditions and the presence of other components in the margarine, some of which are natural antioxidants. As both commercial and technical considerations usually demand that the fatty acid composition of the fats and oils has to be accepted, apart from where hydrogenation is required, irrespective of its susceptibility to oxidation through unsaturation, the important point for the manufacturer is to ensure that the fatty materials are used before they show signs of tending to oxidation.

The milk serum or aqueous phase can be a source of deterioration, as it is a suitable medium from growth of both desirable and undesirable micro-organisms. With good pasteurization and control of the milk and the bacterial cultures used, as described under milk treatment, the risk is principally from infections from the air or the plant, tools and packing materials. Hence regular and systematic cleaning of rooms and plant, and the use of clean packing materials is essential. Regular bacteriological control is a great aid to ascertain sources of trouble. If the margarine shows excessive hydrolytic rancidity it is nearly always the sign of faulty microbial activity.

Of the ingredients used in margarine, salt is added principally for its taste, and the proportion varies with consumer preferences; in some places it may be as high as 3 per cent or more. When 1·5–2 per cent are present in the margarine, the concentration in the serum, 10–12 per cent, is high enough to have a preserving effect by checking the development of many types of bacteria (see page 103), but when only 1 per cent or less is present the effect is only moderate. While 2 per cent or more offer some protection against deterioration by bacteria, it tends to increase the susceptibility of the fat to oxidation, if it contains the more highly unsaturated glycerides and, particularly, if the acidity of the serum is below a pH value of 5·8–6. Generally, it seems that a salt content of 1·3–1·75 per cent is the most favoured, giving a mild salty taste and a fair preserving effect.

The compounds normally defined as chemical preservatives (see page 105) are added for their inhibiting or retarding effect on growth of micro-organisms and thereby defer onset of hydrolytic rancidity and development of sourness and staleness. In the proportions allowed by the regulations in different countries for boric or benzoic acid derivatives the preserving effect is only moderate, but definitely positive, as many years' experience has shown. The combined effect of salt and chemical preservatives is still better. Boron preservatives can be used either as boric acid or as the sodium salt borax or, preferably, as a mixture of the two which permits an adjustment of the serum acidity at the same time. Sodium benzoate is only effective under acid conditions, which liberate the active benzoic acid; benzoate is, however, soluble in the margarine serum, whereas benzoic acid is practically insoluble. Other benzoic acid derivatives, esters of p-hydroxybenzoic acid, are stronger preservatives, but, where permitted, are only allowed in much smaller proportions.

Of fairly recent date is the use of added antioxidants as preservatives against tallowyness, to which reference has already been made (page 121).

While most of the ingredients used in margarine carry but little risk of introducing infection, there is a potential danger of this from egg yolk, sometimes used as an emulsion stabilizer and as an aid to browning, and from flour or potato starch, which is a compulsory ingredient in some countries as an indicator substance. Some factories, using egg yolk, pasteurize it before adding it in the churn, but it loses some of its emulsifying value by this process. Fortunately the micro-organisms, which may be found in it, are kept well in check or eliminated by a vigorous lactic acid population in the milk ingredient and its low pH value. It is more difficult to ensure freedom from micro-organisms in flour or starch, but the use of a clean low-moisture material, stored under dry conditions, lessens the risk; furthermore, most of the organisms in question do not thrive well at the pH value of ripened milk margarine.

Processing and Cleaning.—Of equal importance with composition and ingredients in ensuring good keeping quality are the precautions taken at the various steps in the processing.

Fatty raw materials in the liquid form should be stored at the lowest temperature compatible with keeping them fluid. Where they are in contact with heating surfaces, these should preferably be heated by water; steam might give a too steep temperature gradient and cause overheating of the layer contacting the metal surface. Minimum exposure to air should be the rule, and tall narrow tanks are better than wide shallow ones, within the limits of constructional considerations. Materials inert towards fats, such as for example stainless steel and aluminium, are best from a quality point of view, but tinned steel and steel coated with enamel or some of the modern baked-on plastics, such as Lithcote, are satisfactory, if the coating is kept in good order. Ordinary steel is, however, cheaper and most widely used; it is satisfactory if kept dry and free from rust. Particular attention must be paid to the bottom and lowest part of steel tanks, where moisture and sediments from the stored oil collects in course of time. Some oils contain traces of moisture and colloidal particles of bleaching material, in spite of apparently satisfactory filtration, and during storage, particularly if prolonged, a thin layer of moisture and colloidal matter may collect at the bottom and cause corrosion of the steel there and degradation of the oil with excessive f.f.a. development of the contact layer. Special care should therefore be taken to clean the bottom of storage tanks frequently. Copper and brass fittings must be avoided in the construction of cocks, valves and gauges.

The importance of choosing the right metals for the milk treatment plant has already been referred to in that chapter. The ripened milk may contain up to 1 per cent lactic acid, and sometimes citric acid and salt is added to it before emulsification; it is therefore fairly corrosive towards several metals, and copper and iron particularly should be avoided, as these metals and their salts even in minute proportions of a few p.p.m. act as oxidation catalysts. Tin-coated copper and steel, which have been used widely, are satisfactory only if the coating is quite free from pinholes or abrasions, and the slightest exposure of the metal underneath must be eliminated. The ripening process should preferably be so regulated that the finished cooled milk is not kept for more than a few hours before use, as a slightly bitter taste may develop as the result of changes in the aroma substances under secondary bacterial activity. Cleaning of plant used for such a perishable material as milk is a most important task to ensure that sources of infection are eliminated. Pumps and pipelines should be detachable, easy to dismantle and suitable for cleaning and sterilization; tanks and pipelines used for milk or similar liquids should after emptying be rinsed with hot water, hot soda water or other detergent solution and sterilized with steam. Very dilute nitric acid is often used for plate pasteurizers, and disinfectant solutions, where steam sterilization cannot be applied.

Similar rules for cleaning apply everywhere in the factory, where margarine is treated. The replacement in modern factories of wooden kneading and transportation plant by metal or granite, as well as the change from wet cooling to the dry system, has lessened the risk of infection, but by no means eliminated it, as margarine may lodge in corners and crevices in the plant, and the risk of infection from the air is always present, even in air-conditioned rooms. Where wood is still used, special care is necessary, and scrubbing and rinsing with warm water and soda water is required for removal of grease, and treatment with disinfectant for sterilization. Wooden plant lying idle should be kept damp to avoid the development of cracks, and it should be well covered with salt or lime. As disinfectants, solutions of hypochlorite or chloramine have found wide use and, for wood, of ammonium bifluoride or a mixed solution containing 2 per cent hydrochloric acid, 2 per cent formaldehyde and 2 per cent sodium fluoride. These solutions must be washed away with hot water before the wooden plant is used again after cleaning; they are particularly good for overnight protection. In selecting detergents and disinfectants consideration must be given to their possible effect on the plant material, to their odour and to their ease of removal after use. Some contain ingredients, whose presence even in small traces in margarine is illegal, as well as harmful to the flavour. Many proprietary preparations are on the market, and the margarine manufacturer should satisfy himself that they can be safely used for their purpose.

What has been stated about dairy plant applies also to all other plant and machines for margarine. They should be accessible, easy to inspect and, as far as possible, to dismantle; they should be constructed of material, which has no adverse effect on the margarine and is not corroded by the cleaning materials.

Salt and salt solutions, which are prepared for addition to the ripened milk or to mixing tanks or churns, should be stored in containers inert against strong brine; stainless steel is preferred as a non-coated metal, but enameled or tinned tanks are at times used; steel tanks will soon corrode. Pipelines for salt solutions should preferably be of stainless steel; ordinary steel pipes constitute a danger of rust getting into the margarine.

Emulsification and the emulsion system play a significant part in the keeping quality of margarine. If excessive air is beaten into the emulsion in the churn, it may, even at the moderate temperature ruling during the process, set up incipient oxidation by formation of peroxides in the fat, owing to the very fine dispersion of the air. Speed of agitation during churning must therefore be related to some extent to the thickness of the emulsion; the incorporation of some air cannot be avoided, if the churning method is designed to create a thick emulsion, but much of the occluded air is released and vented through the ventilators of the churn, when the contents are warmed up and the emulsion made more fluid before being discharged to the cooling plant. If the emulsion system is a definite water-in-oil type, the margarine is more resistant towards hydrolytic rancidity, caused by infection from outside, as this is mostly with the type of organism that requires air and moisture for development, and in the mentioned type of emulsion the droplets of the aqueous phase are largely coated by the surrounding fatty phase, particularly if they are in extremely fine dispersion. The oil-in-water type emulsion is more vulnerable to deterioration by infection, but is practically never used for margarine. The mixed type of emulsion, which is, however, always predominantly of the water-in-oil type, is, when the dispersion in the outer fatty phase is fine, practically as resistant as the pure water-in-oil emulsion. Apart from the type of emulsion, the stability and fineness of dispersion of the aqueous phase has also a considerable influence on the keeping quality of the margarine. While an extremely fine dispersion, in which most of the water globules are of the order of 1–2μ or less, may give a rather heavy and fatty sensation on the palate, it definitely helps to protect the margarine against bacterial deterioration, partly by enveloping the globules in fat, partly because the number of globules is much larger than the number of potentially harmful organisms present in fresh margarine. In a stable emulsion, where the water globules are kept as discrete particles of such small size, there will be a majority which will be sterile, and bacterial growth in those that are infected will gradually cease through lack of nutriment. In a loose emulsion lacking in stability, droplets coalesce and may form continuous films or channels, through which infection may spread. If the emulsion is so unstable that visible loose moisture appears, so-called leaky margarine, the surface gets wet and the danger of mould growth is greatly increased, the moisture with its nutrients providing conditions for development of otherwise dormant spores from the air or packing materials. As stated in the chapter on emulsification, a too fine and uniform emulsion lessens the flavour and aroma effect on the palate; hence a certain variation in droplet size and size frequency distribution is desirable from the point of view of flavour, but the emulsion should be sufficiently stable to prevent loose moisture.

The wet cooling method for margarine, which is still in use in some factories, necessitates the use of very large quantities of ice-cold water in intimate contact with the emulsion. Although pure water is naturally used, it is not practicable to obtain it in sterile condition, and there is consequently a risk of infection as well as of the incorporation in the solidified margarine of some loose water, which is not present in the form of droplets, but as films or sheets spreading through the mass. The principal hazard to keeping quality from the dry cooling system is in connection with the use of steel cylinders for crystallizing the emulsion and steel or copper alloy scraper blades, particularly if salt is present in the emulsion. If these materials are not of suitable hardness, a sufficiently large trace of metal may be introduced into the margarine to have a potential catalytic effect on oxidation. The use of stainless steel, nickel and chromium surfaces in the dry cooling plant has greatly reduced this risk.

A serious possible source of infection is the wooden transport truck, which is still in use in many factories. The joints between sides, end and bottom as well as between individual boards may harbour remnants of margarine and serum, which are difficult to expel by solutions of disinfectants or by hot water. These trucks should be thoroughly washed after each use with hot water, scrubbed with detergent, rinsed again with hot water and loosely covered for steaming out. If, as is sometimes the case, soft wood like deal is used in the construction, the cleaning treatment tends to make the surface soft and spongy,and only hard woods like beech, elm, etc., give satisfactory wear. If a wooden truck is left idle for more than a couple of hours, it should be kept damp and sprayed with a disinfectant solution; it should, of course, be rinsed again with water before use. The use of metal trucks, of stainless steel or aluminium, is a great improvement, but they should be regularly cleaned, and they are easily sterilized with steam.

Conveyor belts for margarine are another source of potential infection, partly from the air, partly from the belt if made of canvas or canvas-rubber composition, as is often the case; if they are in use for a lengthy period without scrubbing and cleaning, an infection may become well established and difficult to eradicate. Pure or synthetic rubber belts are better, but may give off rubbery or chemical odour, when rinsed with hot water. Metal conveyor belts are now well established and are the safest and easiest to clean.

Many factories still use wooden kneading plant, but the wood is then always of the hard close-grained type. For some qualities of margarine and for certain kneading operations, such as turn-tabling, damp wood is still the best contact material for effect, but the usual precautions as to frequent cleaning and disinfecting are essential. Kneading plant of the smooth roller type is now practically always made with rollers of metal, stone or procelain and therefore easier to keep clean. Processing on kneading plant can influence keeping quality of margarine, in as much as excessive pressure and shear on a product that is too cold and hard when kneaded, i.e., the temperature at kneading is not adjusted to the composition, can tend to break or coarsen the emulsion and thus cause the exudation of loose moisture, which, as explained earlier, is always a hazard to keeping quality. Where roller or table kneading is followed by high-speed blending, the emulsion may be tightened up again, but some of the moisture will be dispersed as films instead of as globular droplets and therefore may help to sustain bacterial life.

The closed system of continuous kneading in plant constructed entirely of metal offers good protection against some of the risks of the open system, but kneading pressure and temperature must be related to the composition to avoid damage to the emulsion and unevennes of texture.

In connection with packing and wrapping machinery it is important to avoid fragments of margarine being trapped in crevices and intricate parts of the mechanism, and modern machines are provided with automatic stopping arrangements, if for some reason the wrapping paper fails to arrive at the wrapping station; the soiling of the plant with unwrapped margarine is thus avoided. These machines are usually constructed for easy cleaning and well provided with efficient guards. Instructions on system of cleaning should be closely adhered to so as to avoid infection risks at a stage, when the margarine presents a large surface relative to quantity. The construction, pitch and speed of the conveyor worms in the moulding machine should give the coreect propelling force and minimal kneading to avoid streakiness and lumps in the margarine, which should have a suitable temperature and consistency, within certain limits, to get the best effect from the machinery.

Precautions, which should be observed in connection with packing and wrapping materials are referred to in the chapter on these materials (page 252).

Process rooms should be light and airy, but too strong daylight or direct sunlight should be avoided, as intensive daylight may initiate surface oxidation, and direct sunshine may cause softening of the surface over a harder core; subsequent kneading may then cause streakiness and darker spots in the product. Ventilation and circulation of conditioned air is an advantage only, if in addition to temperature and humidity control there is also some satisfactory filtration or cleaning of the air. If this is not done, quiescent air with natural ventilation is preferable. Walls, floors and ceilings should be of a design and material which permits periodical cleaning down. Paints should be of the hard glossy type, and the pigment should be suspended in a vehicle that does not support growth of micro-organisms. Many surface coatings will, under the humidity conditions of margarine processing rooms with the frequent washing down with hot water, provide a good medium for growth of micro-organisms. Tests and experience have shown that if the relative humidity is below 70 per cent, this danger is considerably reduced. Another source of air infection is dust from conveyor belts for dry materials, transmission belts for machines, etc., and these should if possible be avoided near process plant, where naked margarine is exposed. Modern plant is as far as possible driven by direct motors, if necessary through reduction gears.

V. PROCESS CONTROL

Raw materials, ingredients, intermediate and final products, processes and yields are controlled by a more or less elaborate system of chemical, bacteriological and quantity analyses. How extensive these controls are depends on the facilities available and the magnitude of the production, but even in small factories some analytical control is necessary to ensure compliance with statutory requirements as to moisture content, minimum fat content, etc. A survey is given in the following paragraphs of scientific and technical control systems, which, though too elaborate for some factories, are used in many to ensure regular and uniform quality of the manufactured product and elimination of spoilage. While analytical tests are referred to, details of the methods are not generally given and, the reader is advised to consult special books on chemical, physcial and bacteriological methods of analysis [182] [183] [184] [185] [186] [187] [188] [47] [51] [53] [54] [55] [107].

1. Chemical Control

Fatty Raw Materials.—While at times it may be necessary to test fats and oils for adulteration or accidental mixing before delivery to the margarine works, such tests cannot be considered regular process control methods. They demand considerable analytical skill, often consume much time, and require experience in interpretation. Normally, whether the raw materials are obtained from a local refinery or from outside suppliers, a few tests should provide the operator with the required information to guide him as to their suitability for a particular blend, after having been passed for flavour quality. Such routine tests are those for free fatty acids (f.f.a.), iodine value (I.V.) and, in the case of solid fats, melting point (m.p.).

Suitable values for I.V. and m.p. have been mentioned in the chapters on individual fats and oils. Those that have undergone refining treatment, and that applies to most of them, should have f.f.a. less than 0·1 per cent, preferably less than 0·05 per cent. A few liquid vegetable oils, such as olive oil, sesame oil and groundnut oil, obtained by cold processing of fresh fruit and seed, may be used after simple filtration, and may then be satisfactory for some blends even with a f.f.a. percentage up to 0·5, but they are now rarely met with, and if obtainable are mostly used for salad oils. Similar f.f.a. percentages are permissible in animal fats of high grade, for example, Extra oleo, Neutral lard, Extra premier jus, etc.

Melting point and iodine value of animal fats and palm oil vary fairly widely according to source, fractionation and processing, and this must be taken into account in adjusting the proportion in the fat-blend.

While f.f.a. percentage and iodine value are the principal check tests on liquid oils, it is useful in special cases to ascertain, to which extent unsaturation is due to more unsaturated acid radicals than oleic; this can be done, for example, by the thiocyanogen value determination.

It should be a rule with all oils and fats, that they are tested for peroxide value before being used for margarine, for example by the Lea test [124] [125] or some similar test, as a good indication of their susceptibility to oxidation is obtained thereby. Most oils and fats, when well refined, should immediately after deodorization have Lea figures below 0·3, expressed as ml 0·002 N thiosulphate solution per g fat by titration under inert gas, though some oils with linoleic and linolenic acid chains may be somewhat higher, 0·5–0·8. If kept in store a few days they usually show higher figures partcularly oil kept liquid and containing linoleic and linolenic acid radicals, such as cottonseed and soyabean oils, which may as high be as 3–6, and they continue to increase more or less rapidly, according to conditions of storage. Most other materials, if fresh or stored at cool warehouse temperature, should be below 1·5–2.

Hydrogenated fats should show the melting points and iodine values to which they have intentionally been processed. It is however, possible, as explained in the chapter about hydrogenation, to obtain fats of the required slip melting point and iodine value, which vary considerably in firmness, according to the course of hydrogenation. If hydrogenated under the conditions favouring minimal "iso-oleic" formation, it is much softer in consistency, than when processed to give maximal isomerism. This applies particularly to fats with iodine values 60–80, and as for margarine a fairly high "iso-oleic" content is usually preferred for reasons of consistency and to give the expected solid fat effect, it is useful to examine these fats occasionally for "iso-oleic" acid content, either by a chemical test such as the determination of the iodine value of the solid acids, separated under a standardized technique, for example the Twitchell procedure with alcohol or the lead-salt-ether method, or by a physical test such as the dilatation test. The semi-hydrogenated fats for blending for margarine should preferably have 20 per cent "iso-oleic" acid or more and rather steep dilatation curves, showing at 20°C about 30–40 per cent solid glycerides and at 30°C 12–20 per cent with complete melting at 33–35°C. Where used as complete fat-charge it should show 20–25 per cent at 20°C and 10–15 per cent at 30°C. Hydrogenated fats with melting point above 40°C and iodine value below 55 are low in "iso-oleic" acids.

The interval between the mixing of the oils and fats in the blend and the use of this in the emulsification process is rarely long enough to permit, chemical and physical check tests on the blends, but it is advisable occasionally to check the melting point, and if possible the dilatation, of the blend, owing to variations which may be found in individual batches of animal and hydrogenated fats.

Where sesame oil is used as a compulsory indicator ingredient, its reactivity in the Baudouin reaction should be ascertained. Statutory regulations often specify the reactivity of the oil and methods of test. (See also chapter on ingredients, page 114.)

Milk and Milk Derivatives.—The most important control of milk is connected with the biological aspects and will be dealt with under Bacteriological Control. Although the chemical composition of milk does not affect the process economically, as it does the dairy industry operations, there are some chemical tests, which are demanded by efficient control.

Where whole milk is received, it should be tested for fat-content and solids-not-fat; the specific gravity is also often ascertained. A test for acidity by one of the methods referred to on page 67 by titration or by the alcohol test, is important, and if the milk is expected to be received in the pasteurized condition, it is useful to examine it by a test indicating the temperature to which it has been heated.

Milk received as skim milk need not be tested for fat-content, but otherwise the same tests should be applied as to whole milk. Both are tested for biological purity by the combined reductase and fermentation test, although the interpretation of the results differ slightly between pasteurized and unheated milk. Some manufacturers make this fermentation test both at 37°C and at 20–25°C on skim milk to obtain better information about the types of organisms surviving the pasteurization. To aid the interpretation of tests for the biological quality of incoming milk its temperature on arrival should be recorded.

Tests for milk powder and its solutions are indicated on page 79.

The ripened milk at the various stages from starter cultures to finished margarine milk should be tested at each stage for flavour and acidity as described in the chapter on ripening. It is very useful occasionally to support the organoleptic flavour tests with chemical tests for volatile acidic products in the ripened milk, as described in the "volatility" test (page 83) and with tests for diacetyl content. Some tests for diacetyl and acetoin are rather elaborate, such as gravimetric tests of these compounds as nickel-dimethylglyoximate [189] [190] [191], but for running control a modification of the Vosges-Proskauer creatine test is very useful and simple, although not giving strictly quantitative results. There are various procedures for this test, as described by O'MEARA [192] or by HAMMER [193]. A modification, which has been found very useful, requires of reagents only a 0·5 per cent creatine solution in distilled water and a 33 per cent sodium hydroxide solution. 1 ml creatine solution, 2 ml ripened milk and 2 ml sodium hydroxide solution are mixed and shaken intermittently during 10 minutes, when a red colour develops, if diacetyl and acetoin have been formed by the bacteria, the depth of the colour corresponding to the aroma substances present.

Ingredients.—The importance of the quality of the salt for margarine was emphasized on page 104, and methods for testing it are described in British Standards Institution Specification 998, 1941. Most high-grade vacuum-dried finely ground dairy salt qualities comply with the specification.

Where chemical preservatives are obtained ready mixed as branded products, knowledge is required for boron products as to their actual content of boric acid, H_3BO_3, as the addition permitted by the regulations in some countries is based on the pure acid. Similarly, if benzoic preservative is obtained as a mixture of the acid and the sodium salt, the percentage of each should be ascertained, as only the free acid is effective.

Strict regulations are in force in many countries as to which artificial colourings, whether natural or synthetic, are permitted—in some countries no colouring at all is allowed—and in recent years colour regulations have often been changed; hence it is essential, where branded products are bought for use in margarine, that the identity of the dye should be known, or a guarantee obtained from the colour maker as to its suitability and purity. If colour solutions are used, their freedom from turbidity and sediment should be ascertained. Tests for resistance to bleaching by light, as described in the chapter on colours, page 109, or a test on margarine or fat exposed to strong light, should be carried out, and in some countries it is required that the colour should be non-extractable with hydrochloric acid, in which case the margarine or colour solution after shaking with an equal volume of dilute hydrochloric acid should after separation leave the acid layer uncoloured.

If egg yolk is used as an ingredient, it is useful to analyse it occasionally for moisture content and use the residue from that test for determination of fatty matter by extraction with ether. The extracted fatty matter can then be dissolved in an ether-alcohol mixture and examined by titration for free fatty acids, calculated as oleic acid. Old egg yolk shows a considerable hydrolysis of the fatty matter. It is also useful to examine egg yolk for the possible presence of preservative, such as boric acid, benzoic acid or sodium fluoride as these are used at times by producers for material for export to countries where they are permitted.

An ingredient like vitamin concentrate is usually obtained from special manufacturers with a guarantee of potency, which from reputable makers can be relied on. The potency stability of the concentrate from such makers is also generally satisfactory, but it is advisable to receive fresh supplies at fairly short intervals not exceeding a month. Though these concentrates have good stability, unsuitable manufacturing methods and the influence of various ingredients or raw materials in the margarine may affect their stability in the final product, as referred to on pages 120 and 283. Margarine makers with well equipped laboratories often check the potency of concentrates; for vitamin A the spectrophotometric method of measuring the extinction coefficient at 325–328 mμ wavelength on the concentrate itself or on its extracted unsaponifiable matter or measuring the blue colour developed in the Carr-Price antimony trichloride test have mostly superseded the biological test on animals. For vitamin D a biological test is at present the only fully reliable one. These tests are subjects for specialists and require elaborate instruments and careful technique, and they are therefore outside the scope of many factories.

The colorimetric test, the Carr-Price test, in which the blue colour, that is developed when a solution of antimony trichloride in chloroform is added to a vitamin A solution in chloroform under a standardized proceedure, is measured against standard blue glasses in a Lovibond or similar tintometer, can serve as an approximate check test on vitamin A concentrates and is simple enough for most control laboratories. There is no exact method, of converting the blue-value reading into international units, but approximate conversion factors can be established on the basis of tests on concentrates of known potency. Adopting the Carr-Price technique factors of 24–32 have been used according to type of concentrate from fish and mammalian liver oils.

Vitamin D is either present in the desired ratio in the vitamin A concentrate or is supplied as a separate solution in oil of declared potency. Some manufacturers draw their supplies as the crystalline pure ergo-calciferol D_2 of a potency of 40 million international units per gram. Special precautions in selecting the oil for use as a solvent, and in weighing and dissolving the crystals must be observed, as explained on page 118. An antioxidant is often added to the solution.

Tests on margarine, where the vitamins are present in very great dilution, will be dealt with later.

Exploratory tests for antioxidants are mentioned on page 121 and for emulsion stabilizers on page 129, but in both cases it is recommended that new consignments are tested in full factory tests, as composition and processing conditions may modify or even invalidate results from preliminary laboratory tests.

As water is frequently used as direct addition to milk, various ingredients and margarine itself, it should be tested periodically by chemical analysis, particularly for the possible presence of iron; this, if present, may be responsible not only for a bitter taste, but also as an oxidation catalyst for premature and accelerated development of peroxides.

Process and Product.—Chemical control tests during the process are usually limited to examination for moisture and salt, if the latter is added at some stage before the final blending. Excess moisture above the statutory limit, if present from emulsification or from wet cooling, should be worked out during kneading, and this operation should be adjusted to allow the moisture percentage to approach the legal limit as nearly as practically possible or advisable. A small deficiency in water and salt content can in the discontinuous process be made up in the final blending.

As results are required rather quickly to avoid holding up the process, various rapid procedures for examination for moisture with an accuracy of a few tenths of one per cent are adopted, which will yield results in 10–15 minutes. Uncertainties are principally due to sampling, as only 10–20 g are used in the test representing often tons of margarine, which at that stage is not fully homogeneous. The rapid tests are usually carried out by heating the margarine in an aluminium or stainless steel beaker and carefully boiling off the water over a naked flame or on an electrical hot-plate; weighing is done after the sample is cooled down to room temperature. A more elaborate and protracted method is used on the finished margarine. Salt determination can for example be done by titration of the prepared sample of margarine with decinormal silver nitrate, using potassium chromate as indicator.

A number of tests are made on the finished product. The moisture content of the packed qualities as well as their content of fat and solids-not-fat (S.N.F.) should be determined, partly to ensure compliance with legal requirements, partly because the information in many factories serves as a basis for yield and cost control. For this reason a more protracted and exact method is used for moisture determination, and sampling is more reliable, as margarine at this stage is more homogeneous. About 10 g margarine are weighed out and dried in a shallow basin in a drying oven at 105°C until constant weight, as indicated by a loss of less than 0·1 per cent after repeated drying periods of about 30 minutes after a first period of one hour. The moisture percentage is then calculated from the total loss of weight from the original weight. Non-fatty solids are determined by giving the residue from the moisture test some further short drying at 120°C, cooling down and extracting it with ether. The filtered residue after ether extraction gives the non-fatty solids, and the filtrate after evaporation of the ether gives the fat percentage. There are several variations of this test. The determination of salt has already been indicated above; its percentage is included in the non-fatty solids together with milk-solids, preservatives if any, starch and other non-fatty ingredients.

A test for the tightness of the emulsion in the finished margarine and tendency to exudation of moisture, apart from microscopical studies of the dispersion, is in many factories done by means of indicator paper, as proposed by SÖNCKE KNUDSEN [194]. This paper is a special grade of filter paper, impregnated with an indicator solution containing, for example, bromophenol-blue, which changes from yellow to blue, when the pH changes from

3 to 4·6. The paper is dried in air, and in the test it is spread on a freshly cut surface of the margarine, usually to cover an area of 30 sq. cm.; it is pressed gently, but closely to the surface, care to be taken not to slide it sideways, and droplets, which are considered too large for a good disperison, will wet the paper, whereas the suitably small droplets do not affect it. As the pH of the paper, where wetted by the droplets, is increased by the aqueous phase, darker spots develop, where larger drops are present, and the tendency to exudation of moisture can be estimated by the area and number of dark spots. Some margarine manufacturers prepare their own indicator papers and may use other colour indicators. Others purchase prepared papers as, for example, the Presto paper from *Chr. Hansen's Laboratory, Ltd.*

The melting point of a margarine is generally defined as the melting point of the fat-blend. This does not alter during the process, and if it is determined for the blends, it is known for the margarine. Accidental mixing may, however, take place during the process, particularly in the continuous process, when change from one quality to another takes place, and it is useful to check the melting points of appropriate lots of separated fat from finished margarine. It is usually done by the "slip point" method in open capillary tubes of about 1 mm diameter by standardized procedure. Some manufacturers make the test on the margarine itself, but owing to the presence of air bubbles in the margarine and the varying state of emulsion the accuracy of the test is inferior to that made on the fat.

The fat in the finished margarine is examined for acid value (A.V.) or free fatty acids (f.f.a.) to ascertain whether any significant hydrolysis of the fat-blend has taken place during manufacture. The result is usually expressed as A.V. instead of percentage f.f.a., because of the varying molecular weights of the fatty acids in the blend. A.V. is defined as the number of milligrams potassium hydroxide required to neutralize the free acids in one g fat, and it is very nearly twice the figure giving the percentage free fatty acids, if these are calculated as oleic acid with molecular weight 282. An A.V. of 0·3 would therefore correspond to 0·15 per cent f.f.a. as oleic. The fat-blend before the process is rarely above 0·2 A.V.; it usually increases slightly during the process, particularly if the margarine is churned with ripened milk, and various ingredients may also contribute, but a freshly made margarine has rarely a higher A.V. than 0·3–0·35. If it is significantly higher, compared with what would be expected from the f.f.a. percentage of the blend, it may be due to infection with fat-splitting organisms or to faultily refined fats, particularly of the coconut oil group. It is advisable to keep control samples of margarine for several weeks for weekly examination for A.V.; it should increase only very slowly, for example from 0·2 when fresh to 0·35–0·4 in five weeks. If the increase is higher and more rapid, the above-mentioned causes should be considered, or possibly a loose emulsion and "leaky" margarine.

It is also useful to examine the fat from fresh margarine and from stored control samples for tendency towards oxidation and tallowiness by determining the peroxide value by one of the earlier mentioned tests, for example, the Lea test on the separated fat. It is not possible to indicate exact figures for peroxide value, which can be permitted in saleable margarine, as the critical level of organoleptic perception of incipient rancidity varies with the fats and oils used, and is considerably higher with oils containing radicals of linoleic and linolenic acids. It is therefore more the increase over a period, that is informative, than the figure itself. There is always a slow increase, but a rapid increase in the figure may be due to old fatty raw materials, excessive admixture with or exposure to air during the process, contact with oxidation catalysts such as copper alloys or iron, exposure to strong daylight, too high temperatures during processing, etc. It has been mentioned in earlier chapters that a low pH in the margarine serum, coupled with a high salt percentage, increases the susceptibility towards the type of oxidative rancidity, described as "fishy."

In many factories the determination of the acidity of margarine serum is a regular control test. This acidity may be rather different from that of the prepared milk or aqueous phase, as the result of added ingredients and neutralizing compounds. The serum is separated from the fat of the melted margarine, usually by centrifugation, and the fat-free serum tested for acidity either by titration against decinormal sodium hydroxide or by electrometric determination of the pH value, for example, in the quinhydrone or the glass electrode apparatus. The pH value can also be determined with fair approximation in a Comparator against standard colours or by means of indicator papers, which are obtainable in series giving pH values of regular intervals, and which when dipped in the serum give colours for comparison with a standard scale.

In several countries there are statutory requirements concerning the vitamin content of margarine, and even where this is on a voluntary basis, claims are often made by the manufacturers about it. It is therefore desirable, where possible, to check the margarine for vitamin potency when packed, and retained samples after some weeks, to ascertain whether any significant loss of potency has taken place. Testing for vitamin potency is, however, particularly in the high dilution in which these compounds are present in butter and margarine, a very complicated and specialized task and requires expert skill and technique. In the case of vitamin D there is, furthermore, no reliable method except a biological estimate by tests on animals, mostly rats [195].

Vitamin A can be estimated by physico-chemical tests with an accuracy of ± 10 per cent by spectrophotometric measurement of the "extinction coefficient" at certain wavelengths in a specially prepared solution, but that requires also expert operators and fairly expensive apparatus, and it is only possible in large organizations with the necessary elaborate laboratory facilities. Where these are available, the concentrates can be tested, diluted in suitable solvents, by determining the extinction coefficient in ultraviolet light at wavelength 325–328 mμ and applying an accepted conversion factor, 1600–2000 are used according to solvent, to get the result in international units. In margarine, because of the small amount present compared with the concentrate, the estimation is often done on the unsaponifiable matter, which is extracted from the fat by standardized careful procedure and taken up in an organic solvent. in some tests after chromatographic purification. This solution can then be tested by the extinction coefficient method at 325–328 mμ, but a method, preferred by some analysts, is to dissolve the unsaponifiable matter in chloroform and estimate the vitamin A content from the blue colour developed, when the chloroform solution is mixed with the Carr-Price reagent, antimony trichloride in chloroform; the strength of the blue colour is measured in a spectrophotometer and the extinction coefficient converted into international units by a formula, which varies with the different instruments, and by comparison with a calibration curve. A number of publications on this subject have been made in recent years [196–206] [213].

Where these facilities for test are not available, margarine manufacturers usually have to rely on the accuracy of the stated vitamin potency in the purchased concentrate and on the careful measuring out for admixture to the margarine. As mentioned in the chapter on vitamin concentrates, these can be obtained from reliable producers in sealed containers of such quantities as the margarine manufacturer requires for a charge. Although the stability of concentrates from the well-known suppliers can usually be relied on, there is the possibility of mistake or omission in the composition department, or of accelerated losses of vitamin potency through use of fatty raw materials of high peroxide value, pro-oxidant ingredients, excessive exposure to or admixture of air, etc., and consequently the expected potency may not be present in the margarine after processing or a few weeks' storage. A small real or apparent loss nearly always takes place during mixing and processing, even under the most favourable conditions, and a certain excess of concentrate, about 10 per cent, is therefore generally added; furthermore, even the most careful spectrographic tests are only estimates, which may show 5–10 per cent more or less than the real vitamin A content.

There are, however, some rather simple tests for vitamin A, which can guide the manufacturers, though they cannot be accepted as quantitative, only as rough approximations. The simplest is the Fluorescence Test. When a sample of vitaminized fat or margarine is observed under ultraviolet light, for example, from a mercury vapour lamp after passing a Wood's screen, it shows a yellow fluorescence, whereas non-vitaminized fat and margarine show a blue fluorescence. Strongly yellow oleomargarine and unbleached palm oil also show some yellow fluorescence, but in the proportions they may be present it is much less than in properly vitaminized margarine. Carotene added as a colouring agent or for part-vitaminization can also show some yellow fluorescence, but if the vitaminized fat or margarine is compared with a blank corresponding product, which has not had the vitamins added, the difference is at once noticeable, and an experienced observer can estimate roughly whether there is any considerable deficiency in the proportion of concentrate present. The test can only be applied as a rapid and rough sorting guide during processing, but it takes only a few seconds.

Another somewhat more quantitative test, which takes ½–1 hour, is useful to apply to finished margarine and to retained control samples, where elaborate intruments are not available. It is the Dilution Test, originally described by Andersen and Nightingale [207]. It is based on the Carr-Price reaction of a chloroform solution of antimony trichloride with a chloroform solution of the unsaponifiable matter from the margarine, and assessing the intensity of the blue colour developed. As this colour is unstable and fades rapidly, it is not possible to give it a numerical value by tintometer or other comparison; the measurement therefore takes the form of a "dilution" test, in which the solution of the unsaponifiable matter in chloroform is diluted, until the blue colour with antimony trichloride is just perceptible as a rapidly vanishing flash of pale colour, when the two solutions are mixed The degree of dilution is then used as a measure of vitamin A potency and can, by calibration against preparations of known potency be expressed in international units per gram (i.u.p.g.). It is, however, emphasized that the test is only of limited accuracy, and each tester may have his own vision as to limit of dilution, but can compensate for them in the calibration. For example, one operator might find that a sample, which by the more exact and elaborate spectrographic test shows a potency of 20 i.u.p.g., will show a dilution test of 60 and must therefore use a conversion factor of 0·33; another operator may assess the dilution as 50 and will use a factor of 0·4. Oxidized fats and oils with high peroxide figures give a poor greenish blue colour or brownish green, but in spite of its limitation the test, when carried out by the standardized technique, provides good guidance to the factory control. Often it is sufficient to decide on a minimum dilution test, which a sample should show, and test it right away at that dilution.

Test for carotene content, whether added as a colouring or as a provitamin A, have been described by Morton, Lord and Goodwin [208] and by Taylor [209].

In some factories control tests are made on Cake and Pastry margarine to check their preformance for the purpose, for which they have been specially made. Cake margarine may, for example, be tested for "creaming power" by a standardized empirical test such as described on page 256, and Pastry margarine for "puff" pastry may be tested for extensibility by preparing flat plates of dough with a definite number of foldings, and measuring increase in volume after a standardized baking procedure. Margarines for short friable and tender pastry and crust are sometimes tested for "shortening value" by making test biscuits and measuring the "breaking strength," i.e., the weight or power required to crush or break them under defined conditions by means of a so-called shortometer. The test is, however, difficult to standardize and has found more application in tests for biscuit fats and 100 per cent fat shortening than for margarine.

In many countries, where butter quality is assessed by a "points score," the largest proportion of points in grading is allotted to taste and aroma, but 20–25 per cent are usually allotted to texture and consistency. Where margarine is similarly graded, the variation in the score for consistency is usually wider than in butter, owing to the wider difference in the chemico-physical characteristics of the fat-blends and in processing methods. Consistency of margarine, with which is connected plasticity and spreadability, is usually assessed by subjective judgment by experts, who by digital pressure on a sample, and taking into consideration the temperature at which the test is made, can assess very closely the rheological properties in relation to its usefulness for various purposes. Such tests are made at the various stages after solidification of the emulsion and compacting of the product by kneading, and they serve as guidance for adjustment of later processing conditions. Consistency is temperature-dependent, and with many margarine compositions more so than with butter. The various instruments, which have been devised for assessing or measuring consistency in butter, by compression of small cylindrical samples between parallel plates, by impact of falling bodies, sagging tests, sectilometers, penetrometers, plastometers, extrusion instruments, etc., have not proved sufficiently informative and selective for margarine, where the state of the solid emulsion, air content, crystalline state of the fat and the glyceride composition all play a part in defining the consistency and texture. Some of these instruments are used in margarine factories, where however their limited value is realized, but they can serve the purpose of indicating gross deviations from standard routine. Better guidance is, in the opinion of many margarine manufacturers, obtained by the subjective method, augmented by knowledge of the physical glyceride composition as given for example, by dilatation tests. Instrumental tests for rheology of margarine and butter have been described by BARON [210].

In view of the close contact between margarine and parchment as lining or wrapping material it is advisable, where facilities are available to examine the paper for accordance with the quality requirements, as outlined on page 253, for example by the methods mentioned in British Standard Institution's Specification No. 1820, 1952, or similar methods.

Where brine solutions are used for cooling the emulsion, as for example on drums, it is useful to check regularly the strength of the solution, as this often gets gradually more dilute and cannot be cooled to the low degree required, and in such cases it may be the cause of unsatisfactory solidification of the emulsion.

Some manufacturers undertake regularly a much more extensive system of chemical control on raw materials, ingredients, packing materials and miscellaneous materials required in the factory, which of course may be considered an indirect process control, and many also contribute in a great measure to research on materials and processes. It is, however, outside the scope of this book to deal with these subjects.

2. Bacteriological Control

The important rôle played by bacteriology in the technology and preservation of margarine [211] has been emphasized in earlier chapters, and a bacteriological control is therefore highly desirable. Large organizations frequently employ several bacteriologists to maintain an elaborate system of control and for preparing and selecting cultures for milk ripening, but also in smaller factories a limited control system can provide the technical management with guidance and with early warning of potential risks from infections, before they develop too far, or, if they have taken hold, can give information about their source. The two main fields of bacteriological control are in milk preparation and in watching process, plant, ingredients and materials for possible infections with undesirable micro-organisms, which might degrade flavour quality and shorten the keeping quality.

Milk and Milk Preparation.—Some of the chemical tests for milk on arrival and during ripening are in a sense connected with bacteriological control, as they measure the activity of the organisms, and, as regards the combined reductase and fermentation test, also indicates the type of bacteria present, but they are not sufficiently discriminatory as to specific infections, which may, if established, become dominant. While many manufacturers may be satisfied with ascertaining, that the ripening proceeds as desired, as indicated by flavour and acidity test and by only slight deviation in time cycles, others undertake systematic bacteriological tests on samples from the various stages of cultures, factory starters and ripened margarine milk. Direct microscopical examination of the acid milk is of little practical value, as the culture organisms, developed under the most favourable conditions for them, suppress the growth and propagation of most competing organisms and are present in such enormous numbers, 100 millions and upwards per ml, that little else can be seen in the microscope field. Counts of colonies on plates in Petri-dishes are not very informative for the same reason, even after high dilution of the sample, if the medium is similar to milk, for example, milk-serum-agar, but if the incubation temperature of the plate is 4–6 C higher than that, at which the milk is ripened, some of the contaminating organisms will find better conditions for development and may be detected, particularly lactose-fermenting yeasts and moulds, by the appearance of the colonies on the plate, confirmed by microscopic examination. Or the diluted sample of milk may be inoculated into a nutritive medium specially suitable for detecting contamination with foreign organisms, for example malt extract-agar, dextrose-peptone-agar or yeast-salt-dextrose-agar, and incubated at 25° C for 3 days.

A method, which is frequently applied and gives informative and fairly rapid results, uses slopes of nutrient dextrose-agar in test tubes; the medium is tinted with brom-cresol purple. Lactic acid bacteria and all ordinary contaminating organisms give definite growth on this medium in 24 hours at 26–28 C, the acid-forming culture organisms causing a change in colour from purple to greenish-yellow, and many small colonies of these organisms may be faintly seen. Strongly growing forms are usually infections, and yeasts and moulds can as a rule be detected by the naked eye. When the slope culture is 48 hours old, the features are more distinct, but should in cases of doubt be confirmed by microscopical study. The drops of condensed water collecting at the bottom of the slope and which contains the nutrients afford good information by direct microscopical examination.

Process and Plant.—Contamination of the milk in the dairy is rarely serious enough to affect ripening, if pasteurization has been effective and cleanliness of the expected standard, but all further process steps and mixing with blend and ingredients introduce potential risks of further infections, the early detection of which is important, so that the source can be eliminated, before it becomes so well established that the quality of the margarine is affected. Even a minor infection, which may not affect the quality of the milk or the margarine during the process, when the infection occurs, may become serious later, as it finds in margarine a more favourable medium for development, particularly if the infection is derived from fat-splitting organisms or lactose-fermenting yeasts and moulds.

For these later stages the bacteriological examination can be made by means of slope cultures as described, but it is usually found more practical to use plate cultures, employing for general purposes the same nutritive media or such as described in B.S.I. Specification 895 [212]. For a systematic bacteriological control with a view to tracing the origin of infections, which may have caused premature deterioration of margarine in store or during distribution, samples must be examined from as many stages of the process as convenient, for example, of water used in the aqueous phase or for producing ice for direct addition in the churn; of margarine that has been in contact with wooden processing plant; of the finished margarine; of ingredients of perishable nature such as egg yolk and starch; of wrapping material which comes in direct contact with the margarine surface, etc. A frequent source of infection is the air in the process rooms, even if this is treated in air-conditioning plants (see page 275). Living micro-organisms and spores are carried in from the outside air or absorbed in the air from various materials, from contact with walls, ceilings, floors and human beings. An indication of the infection risk from the air is obtained by exposing sterile Petri-dishes with appropriate nutrient gelatine or agar, preferably with brom-cresol purple as indicator, in the rooms to be examined; an exposure for 10 minutes of the uncovered dish will usually suffice for giving a deposit, which will develop a suitable number of colonies after incubation at 26° C for 3–5 days, but the exposure time may be varied in accordance with the suspected degree of contamination. The result is usually expressed as the number of organisms deposited per minute per square foot. There is no actual standard for what may be considered an excessive count of micro-organisms, as the risk to the quality of the margarine depends on the types of organisms, the resistance to them of the margarine and the exposure of this to the air. Where the process is in a more or less closed system and metal plant, the risk is obviously much less than when the product is worked on open and wooden plant. Counts as high as 100 colonies per sq. ft. per min. may not be unfavourable as long as the majority do not consists of yeasts and, particularly, moulds, but in well-kept factories the count is more of the order of 20–30 colonies.

In view of the special risk of infection from the surface of wooden plant, scrapings obtained aseptically from the wooden surface by pressing out contact layers of moisture and margarine are frequently examined after being diluted with sterile water and incubated after mixing with the nutrient medium, for example malt-agar, when examining for yeasts and moulds, or yeast-peptone-tributyrin or meat-whey-agar on a film of solid fat in Petri-dishes, when searching for fat-splitting organisms.

A complete bacteriological supervisory control, as undertaken in some large factories, involves the testing in appropriate media of samples from many steps in the process and places in the plant, for example from milk and milk powder solutions before and after ripening, starters, pipelines, ice plant, hoppers, churns, kneading plant, conveyor belts, wooden tools, transport trucks, and from the margarine during the process, when finished and at intervals on retained control samples. In this way, although the tests take 2–3 days in incubator, before the results are available for interpretation, it is possible to get early warnings of infections, before they become established. In many factories, however, such an elaborate control system cannot be considered, and faults, which may be ascribed to microbial causes, will reveal themselves sooner or later by visible signs of mould growth or by sensory tests; it then becomes essential to search for the cause, and attention must be given to the points mentioned in the chapter on preservation of margarine, pages 267 *et seq.* A clue as to the cause of the various types of deterioration by microbial activity may be obtained from the following points: So-called "perfume rancidity," resulting from the presence of methyl-ketones, is usually caused by moulds, and margarines containing coconut oil and palmkernel oil are particularly vulnerable; the fault can be detected sensorially, before mould growth is visible, and the acid value of the fat is as a rule excessive. A soapy sharp taste, accompanied by excessively high acid value, is mostly caused by fat-splitting yeasts and bacteria. An unclean putrid smell is caused by various special bacteria, frequently derived from impure water or the air. Spots and discoloration result from mould growth, and sometimes a musty smell is caused by certain moulds. A yeasty or sour taste and smell is generally caused by lactose-fermenting yeasts.

It should be realized that the presence of micro-organisms other than those deliberately introduced by means of ripened milk does not necessarily lead to premature deterioration of the margarine; it is only when an infection becomes so well established as to be dominant that the faults develop, and the more frequent type of degradation is in most factories caused by oxidative changes, unconnected with micro-organisms. Many infections, and it is difficult to avoid them entirely, die out before they can cause damage, or are suppressed by more vigorous harmless or culture organisms. Several kinds of bacteria have low acid-tolerance and are therefore checked and often eradicated by the lactic acid formed by the culture organisms. Many kinds have also low salt-tolerance and have little chance of becoming established in margarine of medium or higher salt content, where the concentration of salt in the serum may be 6 per cent or more. Benzoic acid preservative has also a definite suppressing effect on many bacteria, but there are many countries where chemical preservatives are not permitted, and where unsalted margarine is favoured, milk is rarely used, hence the protection afforded by salt and acid serum is absent. Furthermore, where the margarine is solidified by the "wet" process, and where the aqueous phase contains a relatively small percentage of ripened milk, the acidity in the serum may be too low to have a protecting effect against many types of bacteria. The practice in many factories of reducing serum acidity by mixing ripened milk with pasteurized unripened milk or by partly neutralizing the acidity with alkali has therefore some disadvantage, even though it is advantageous in other directions (see page 93). Some of the fat-splitting bacteria are fairly sensitive to acid or acid and salt, but may have caused some hydrolysis of the fat with the resulting sharp taste before succumbing. Other fat-splitting bacteria, both of rod-shape and micrococci have good salt-tolerance, but are vulnerable to acid; if they find their way into margarine, in which for some reason the serum acidity is reduced, they may cause damage by giving rise to a soapy taste. Yeasts have high acid-tolerance and also tolerate salt well; they can therefore go on developing, as the margarine ages; they utilize the lactic and other organic acids and the aroma compounds, thereby reducing the acidity and affording possibilities for wild bacteria to develop. They therefore constitute, particularly the *torulaceae*, a greater danger to keeping quality than do most bacteria. Moulds have also good acid-tolerance. The culture organisms, the lactic streptococci, which are very vigorous and numerous in the emulsion made with ripened milk, gradually weaken under the effect of acid and salt, the aroma producing betacocci being more persistent than the acid-producing strain, and after 3–4 weeks they may fail to develop on slope cultures.

Pathogenic organisms are not found in pasteurized ripened milk or in margarine, where conditions for their development are most unfavourable. Coli-form organisms are rarely found.

From this survey of the bacteriological features of margarine it will be seem, that the flavour quality and preservation of it can be seriously interferred with by unsuitable microbial activity. As stated earlier, in well-managed factories with modern plant the risk is nowadays relatively small, compared with the days when "wet" cooling and wooden plant and utensils were in common use, and deterioration of quality is now more often due to oxidation faults. Pasteurization of the emulsion has been attempted in some factories, but although it is done in a closed system, there is a risk of interference with the right kind of emulsion and pre-crystallization, of introducing minor reactions between ingredients and of over-heating the fat-blend. A good vigorous ripening process and scrupulous cleanliness throughout the process, as well as suitable packaging, will normally give the manufacturer the necessary conditions for avoiding damage to the product from microbial causes.

3. Yield Control

The manufacturer aims to obtain from his principal and basic raw material, the fat-blend, as high a yield as possible, consistent with legal and quality considerations and requirements as to fat and moisture content in the final margarine, and consumer preference concerning salt content. In some factories the terms Outcome or Rendement are used to indicate yield. The higher the water and salt content, the bigger the yield from a certain weight of fat-blend, which latter accounts for the principal share of the total cost.

If, for example, a margarine is made from 100 parts fatty material, including fat-soluble ingredients, 21 parts of skim milk, consisting of 19·2 parts water and 1·8 parts (8·5 per cent) milk solids, 2 parts salt and 0·3 parts solid ingredient, such as starch, the total yield of margarine, if nothing is lost or sacrificed in the process, should be 123·3 parts. The moisture content would be $\frac{100}{123 \cdot 3} \times 19 \cdot 2$ or 15·57 per cent and the fat percentage $\frac{100}{123 \cdot 3} \times 100$ or 81·1 per cent. The salt content would be $\frac{100}{123 \cdot 3} \times 2$ or 1·62 per cent. This margarine would comply with regulations stipulating a maximum water content of 16 per cent, but would fail where the minimum fat content should be 82 per cent or more. The theoretical composition of this margarine would be 81·1 per cent fat, 15·57 per cent moisture, 1·62 per cent salt, 1·46 per cent milk solids and 0·25 per cent starch. To comply with the 82 per cent minimum for fat-content it would be necessary to work to a lower water percentage or to less salt or both, and the yield would be less. An 82 per cent minimum of fat allows a maximum yield of 122 parts margarine from 100 parts fat. If the margarine contains 82 per cent fat and 16 per cent water, there is still room for 1–1·5 per cent salt, as when well ripened milk is used, its proportion in the aqueous phase is sometimes as low as one-third or less, and the percentage of milk solids in the margarine may then account for only 0·4–0·5 per cent.

In practice, however, conditions are somewhat different, and the theoretical yield, as expected from the quantities of the various constituents, is not reached, as there are losses in process as well as losses in yield by sacrificing a small percentage of finished margarine in the form of overweight on the nett weight of dispatched packages to compensate for possible evaporation losses and, in the case of bulk packages, to afford the retailer a certain margin for dividing the bulk to individual customers, for adhesion to lining materials, etc. Where margarine is made by the discontinuous process and given a final treatment in blenders, any loss of moisture during the earlier part of the process, or deficiency in the desired final moisture percentage, can be made up by a limited addition in the blender. Some manufacturers using that process make the emulsion with excess aqueous phase to compensate in advance for moisture losses arising during kneading. Where one of the so-called continuous processes is used and input and output of materials are equal, the yield should only differ from the theoretical by the amount given away in overweight and by losses in cleaning the plant; some of the latter can be recovered as a by-product, useable for technical purposes. There is, however, nearly always a small loss unaccounted for.

A process yield balance sheet from one of these process might be on the following lines, based on 100 parts fat-blend:

Input		*Output*
Coconut oil	35 parts	241 packets of 0·5 parts each Total 120·5 parts.
Hydrogenated fat	15 ,,	
Semi-hydrogenated fat	25 ,,	
Liquid oil	23 ,,	
Liquid oil for fat-soluble ingredients . .	1·5 ,,	
Fat-soluble ingredients (0·2 parts lecithin, 0·2 parts monoglyceride, 0·08 parts vitamin concentrate, 0·02 parts colour solution	0·5 ,,	
Total fatty matter	100·0 parts	
Milk, containing 0·85 parts milk-solids .	10·0 ,,	
Water	11·0 ,,	
Salt	2·0 ,,	
Total	123·0 parts	

This schedule shows that against an input of 123 parts a yield of 120·5 parts has been obtained; there is thus an apparant loss of 2·5 parts. To find how this can be accounted for, an average sample of the finished margarine is analyzed for moisture, fat and solids-not-fat, as explained on page 280, and the result might be: 15·8 per cent moisture, 81·94 per cent fat and 2·26 per cent solids-not-fat, of which latter 1·60 per cent as salt. As the analysis of the input figures shows a composition of 16·38 per cent moisture, 81·30 per cent fat and 2·32 per cent solids-not-fat, including 1·63 per cent salt, the two sets of figures show the following differences:

Input:	81·3 % fat	16·38% moisture	2·32% solids-not-fat.
Margarine finished:	81·94% ,,	15·8 % ,,	2·26% ,, ,,

Theoretical yield from input of 100 parts fat : $\frac{100}{81\cdot 3} \times 100 = 123$ parts.

,, ,, ,, Final figures ,, ,, : $\frac{100}{81\cdot 94} \times 100 = 122\cdot 03$,,

The analysis of the finished margarine shows that processing has reduced the moisture content to 15·8 per cent from the original 16·38 per cent, which was deliberately on the high side for the legal limit of 16 per cent, as experience had shown, that in emulsification, drum cooling, continuous closed kneading, and in the screw conveyor hopper for the wrapping machine about 0·5 per cent moisture in total was usually lost. The theoretical yield could therefore not be expected to be more than 122·03 parts.

The difference between the theoretical yield of 122·03 and the actual yield of 120·5 was found to be explained as follows:

Check-weighing of a number of the wrapped packets showed that the average overweight per packet was 0·7 per cent, which loss was intentionally incurred by setting the moulding and wrapping machine to give an average overweight of about 1·5 g, so as to allow a margin for the slight variation in weight between individual packets, and to allow something for loss of moisture by evaporation through the wrappers between packing and handing over to the customer.

Recovery of spoiled margarine from the process, starting and closing down of the plant, cleaning of pumps, pipelines feeding trough, etc. showed that the amount accounted for 0·5 per cent of the margarine produced. This could be disposed of as technical fat and the value credited to the cost of fatty raw materials, but it was lost to the yield.

The actual output, which could be accounted for, was therefore 120·5 parts packed margarine plus 0·7 parts overweight plus 0·5 parts process waste, or a total of 121·7 parts against the theoretical yield of 122·03 parts, thus leaving 0·33 parts as unaccounted-for process loss.

Summarized the figures in the quoted example are:

	Input Analysis	*Final Analysis*	*Actual Yield*	
Fat	81·30	81·94	Margarine	120·5
Water	16·38	15·80	Overweight	0·7
Solids-not-fat	2·32	2·26	Waste margarine	0·5
Total	100·00	100·00	Unaccounted for	0·33
Yield	123	122·03		122·03

Where the margarine is churned with a fair excess of aqueous phase, as is often the case in the batch process, particularly when "wet" cooling is used, and where salt may be added at various stages during the process, and water, salt, fat-soluble and water-soluble ingredients added in the final blending, the yield analysis must be based on chemical analysis of the final margarine and actual yields compared with the theoretical as indicated from the analysis. The principle is as described above; the percentage given away as overweight, and the weight of recovered waste as margarine must be ascertained to prepare a process balance. For example, the average over a week from a number of samples of certain quality showed:

Water 15·39%, Fat 82·59%, Solids-not-fat 2·02%.

Theoretical yield from 100 fat	121·08
Actual yield from invoice weight	118·30
Overweight	1·02
Waste recovered	1·18
Unaccounted-for loss	0·58
	121·08

As different qualities may vary in the percentage of salt added, the percentage of milk, and therefore milk solids, in the aqueous phase, in the ingredients used, etc., each quality must be considered separately for yield analysis, which is usually made weekly. Owing to the unavoidable small variation in water percentage of individual churnings or batches a suitable number of samples from a week's production of the particular quality should be analyzed, or should be mixed on a weighted average basis and analyzed to provide figures for yield analysis of that quality.

A more or less elaborate system of checking overweight should be arranged in order to provide a sufficiently reliable basis for yield losses from that cause. Most automatic moulding and wrapping machines afford a weight accuracy of ± 0·5 per cent, i.e., 1·1 g on a half pound packet. To be certain that the nett weight is as stated on the packet despite differences in firmness and in conveying and measuring efficiency of the packing machine, and to allow for slight losses by evaporation, which depend on the stability and fineness of the solid margarine emulsion and the vapour permeability of the packing and wrapping material, manufacturers often set the machinery to give 2 g overweight on a half pound or a quarter kilogram packet, which would mean 0·8 per cent loss. When margarine is packed in bulk, 14, 28 and 56 lbs. boxes or similar metrical weight, the overweight is rarely more than 0·3–0·5 per cent.

Where several qualities are made, it is not a practical possibility to segregate waste material from individual churnings or qualities. A weekly recovery figure is usually credited pro rata to the various qualities.

In the quoted examples the yields have been based on the amount of fatty matter weighed into the process. In the cost accounts in some factories the yield is based on the invoiced weight of the fatty raw materials, and as there is usually a loss in weight between the invoiced quantity and that weighed into the process, owing to losses in melting out and emptying fats and oils from their containers, in pumping and storage of raw materials and possibly from the presence of a small amount of moisture, about 0·25 per cent, in the fats as received, the difference between actual yield and that based on the invoiced weight of the fatty matter will be slightly greater than between actual yield and that based on analysis of the finished margarine. Some of this difference may be accounted for as an increase in the proportion of waste fat recovered from steaming and cleaning of casks, barrels, etc., some will be included in the proportion not accounted for.

The actual packed yield is used as a basis for the cost of materials for margarine. Proceeds from the sale of waste fats is generally credited to the cost of the fatty raw materials, to which is added the cost of the milk and the ingredients. This figure, divided by the actual sales or packed weight of the particular quality, gives the material or prime cost per weight unit. To get the manufactured naked cost it is necessary to add expenses for receiving and storing raw materials, processing charges, including wages and salaries, water, power, steam, cooling and light; building services; plant maintenance and repair services; factory services such as stores and supplies, internal transport, cleaning, process overheads such as insurances, depreciation, technical control, etc. To the naked cost is added packing cost, which varies with the unit size of the pack, and is the total of packing wages, packing and wrapping materials, maintenance, power and overheads for packing machinery. Additional to packing cost there is usually a separate cost for delivery to storage and warehouses under manufacturer's care.

How these various costs are allocated to individual process sections and qualities depends on the cost accountancy system adopted in the different factories. It is not possible to give any even approximate indication of cost of production, as wages rates vary widely from country to country, and as manufacturing processes differ from factory to factory. Where plant requiring little manual labour is used, more power is consumed. Costs also depend to a great extent on rate of throughput, unit size of operations, etc. Some factories obtain their power by purchase of electricity from outside and generate low-pressure steam for heating and other process purposes; other factories generate their own electric power and steam of higher pressure. As fairly large quantities of steam of 2–3 atmo. pressure are required for pasteurizing, melting and storing of fats and oils, heating of water for cleaning, sterilizing of pipelines and plant and so on, the margarine factory provides an opportunity for highly efficient and economical utilization of fuel by using prime-movers, engines or turbines, with pass-out or exhaust low-pressure steam, thus providing both motive power and steam for heating. It is however essential that steam, which comes in direct contact with margarine or materials for it, as well as that used for sterilizing pipes and plant, should be pure, free from odour and entrained lubricant. Such steam could be taken direct from the boiler, or high-pressure steam could be used to generate from specially purified water, in a secondary low-pressure boiler, clean steam for special purposes, and the exhaust steam as well as the condensate from the secondary boiler could be used for heating and providing the large quantities of hot water for indirect heating and for general cleaning.

Power requirements in a margarine factory will therefore vary widely according to circumstances. Expressed as kilowatt-hours, kWh, per ton of output fairly modern works show figures of 20–50 kWh according to type of plant. Steam consumption varies similarly from 0·2–0·8 tons per ton of margarine produced; the lower figures being from works with own refinery, which saves the steam for melting the fats. Refinery steam is not included.

Water requirements are particularly high per ton of output in factories with "wet" cooling. It is important that large quantities of good clean water is available; it must be of potable quality where used for addition to milk and churns, and for hot water for cleaning. For indirect heating in coils, etc., and for condensing purposes in refrigeration and power plant, river supplies and similar sources may be used, but the water should be free from sediment and odour and any kind of pollution. In selecting a site for a margarine factory the possibility of obtaining suitable water must be given early consideration.

Labour costs, like the other services, vary naturally with processing systems, scale of manufacture, rates of wages and other factors; expressed as man-hours per ton of margarine manufactured, figures lie usually between 12 and 30, although they may be rather higher in small factories of 20–50 tons weekly output.

VI. LEGAL ASPECTS

The manufacture and sale of margarine is in nearly all countries governed by statutory regulations, covering the principal constituents, the use of preservatives, colouring matters, various ingredients, marking and labelling of packages and types and shapes of these. In addition the regulations deal often with licences and licence fees for manufacture and sale, often renewable yearly, registration of premises, special excise taxes and sales taxes, advertizing, channels of distribution, quotas of production, and in some countries also with specification for composition of the fat-blend. In the latter case it is principally to assist agriculture by ensuring an outlet for certain indigenous raw materials. In United States and in Australia the regulations vary from State to State and in Canada from province to province.

As will be seen from the selection of regulations shown below, these vary considerably from place to place. In some countries they have permitted the margarine industry to develop and carry on manufacture without too great interference; in others the legislation has been definitely repressive, with the result that consumers have not been able to get as good a quality as is possible, where legislation shows a broader understanding of the importance of the product. Until a few years ago there were countries, such as Canada and the Union of South Africa, where the manufacture and sale of margarine was prohibited, to avoid competition with local dairy interests, but the changed world pattern of food production and distribution has made the margarine industry a welcome addition to popular nutrition in most countries.

Fluctuating economic, trading and political conditions, as well as increasing understanding and knowledge of nutritional science, has caused many major or minor changes in margarine legislation in recent years, and some changes occur rather frequently. It is therefore important that those interested should ascertain from the proper authorities in the various countries, what is the state of margarine regulations at any particular time. The details given here cover the present time, January 1954, and deal principally with those sections of the regulations, which concern the technologist and apply to the product. Regulations concerning licences, taxes, fees, advertizing, quotas and government regulations of fat-compositions change frequently and have, except to some extent the last mentioned, no bearing on manufacture.

The countries referred to include the principal producers and users of margarine; some of the minor producing countries are left out. Information is not available about legislation in Russia and adjacent countries at the present time. The regulations in Czechoslovakia, Poland and Hungary, operating before the war, are included.

Austria

The earlier special Austrian regulations were changed in 1939 and superseded by the German. Since the war some changes and compromises have been introduced, and the principal requirements in connection with the manufacture are now as follows:

Butter or butterfat shall not be mixed into margarine. The use of milk is limited to 100 parts by weight, or a corresponding quantity of cream, per 100 parts by weight of fat not derived from milk.

Margarine shall contain not less than 80 per cent fat and not more than 18 per cent water. Salted margarine shall contain not more than 18 per cent salt and water combined.

As indicator reagent margarine must contain not less than 2 parts and not more than 3 parts potato flour per 1000 parts margarine.

As preservative, a maximum of 0·2 per cent benzoic acid or 0·24 per cent benzoate of soda is permitted.

Certain harmless colourings are permitted, and there are no restrictions regarding the use of flavourings.

Vitamin additions are permitted; they are not compulsory.

Small packets shall be in the shape of cubes, larger packs may be in the form of cases, tubs or vats.

Belgium

Margarine must not contain anything harmful, nor glycerine or hydrocarbons, nor any mineral substance except water and salt. Not more than 10 per cent milk fat shall be present. Margarine shall contain not less than 82 per cent fat, and the maximum content of materials other than fat plus salt shall be 15 per cent.

As indicator ingredient not less than 5 per cent sesame oil and 0·2 per cent potato starch shall be used.

No preservative other than common salt is permitted.

No colouring matter extractable by hydrochloric acid is permitted.

Vitamin additions are permitted, but they are not compulsory.

Packets should be of cubic shape and ¼, ½, 1 or 2 kg weight.

Czecho-Slovakia (1938)

There were restrictions regarding production quotas, and compulsory use of certain inland raw materials; also excise tax on production.

Margarine should not contain any butter, have a minimum fat content of 82 per cent, and not more than 18 per cent water.

As preservative 0·2 per cent benzoic acid was permitted, but should be declared.

Colourings not injurious to health were permitted.

As indicator 0·2–0·3 per cent potato starch should be used.

Denmark

It is prohibited to include any waxes or hydrocarbons in margarine. It may contain up to 3 per cent butterfat derived from milk or cream added during churning, but not from added butter. The margarine shall have a minimum fat content of 80 per cent and maximum water content of 16 per cent.

No preservative except common salt is permitted.

Any non-injurious colouring matter, except coal-tar dyes, may be used. No regulations are in force regarding the use of flavourings.

As indicator reagent sufficient sesame oil shall be used so as to give a specified intensity of the Baudouin reaction, usually about 5 per cent.

All margarine must be vitaminized under Government control and shall when sold show a vitamin potency of 20 international units vitamin A and 0·5 international unit vitamin D per g. Of the vitamin A activity 14 units must be derived from vitamin A proper and 6 units from carotene. Only preparations approved by the Ministry of Agriculture may be used, and must be used not more than a fortnight after the container has been first opened. Bakery margarines need not be vitaminized.

Eire

Margarine is any article of food which resembles butter and is not milk-blended butter. It shall not contain any ingredient injurious to health or foodstuffs in any way unfit for human consumption.

It is prohibited to manufacture or sell margarine the fat of which contains more than 10 per cent butterfat and which contains more than 16 per cent water.

The addition of preservatives is prohibited, but the term preservative does not include common salt, saltpetre, essential oils and glycerine.

There is no provision for the use of indicator reagents.

There is no prohibition against the use of harmless colourings or flavourings, but certain colourings are prohibited as harmful.

There are no regulations regarding addition of vitamins.

Finland

Addition to margarine of wax of any sort, hydrocarbons and of chemicals is forbidden, unless permission is obtained from the Board of Agriculture. The following may be incorporated in margarine without declaration: diacetyl, lecithin, alkyl gallates (0·01 per cent), benzoic acid and sodium benzoate (maximum in terms of acid 0·3 per cent), and salt.

Margarine shall not contain more than 5 per cent milk fat and not less than 80 per cent total fat, nor more than 16 per cent water.

Harmless vegetable colourings are permitted.

Not more than 0·5 per cent starch shall be incorporated as indicator reagent.

There are no regulations regarding vitamin addition.

France

Licence is required for manufacture and sale.

The composition of the blend can be regulated by the Authorities.

Margarine shall not contain more than 10 per cent butterfat and 16 per cent water. The total of non-fatty materials shall not exceed 18 per cent.

Preservatives, except common salt, are forbidden, but boric acid addition is permitted for export.

At present no addition of colourings is permitted, but naturally coloured fat can be used. (Colour regulations have changed several times in recent years.)

Flavourings are permitted. Diacetyl is mostly used.

Not less than 0·2 per cent rice starch or potato starch shall be used as indicator reagent.

No vitamin addition is required, but synthetics are prohibited.

Packets must be of cubical shape.

Germany (Federal Republic)

Margarine includes products resembling butter, of which the fat does not solely originate from milk. Rendered margarine or Schmelzmargarine is margarine with less than 1 per cent water.

The raw materials shall be wholesome; the use of butter or butterfat is prohibited; up to 100 parts of milk by weight, or a corresponding quantity of cream, may be used in the process per 100 parts by weight of fat not derived from milk. The final margarine shall contain not less than 78 per cent fat and not more than 20 per cent water and salt.

Preservative is allowed up to 0·2 per cent sodium benzoate or benzoic acid.

Addition of colouring matter is permitted. There are no rules relating to the use of flavourings.

Margarine shall contain either 10 per cent sesame oil in the fatty matter or 0·2–0·3 per cent starch flour, calculated on the finished margarine.

Additions of vitamins are subject to special notification to a competent Board of Health, the Minister of the Home Department reserving a right of veto. Packets of margarine, if vitaminized, must bear a special declaration.

Great Britain and Northern Ireland (U.K.)

Margarine is defined as any food, whether mixed with butter or not, which resembles butter and is not milk-blended butter.

It is an offence to sell margarine the fat of which contains more than 10 per cent butterfat. Margarine may not contain more than 16 per cent water.

Preservatives are prohibited, though as an emergency during the war and for some years after 0·25 per cent boron, calculated as boric acid, was permitted.

No prohibitions exist against the use of harmless colourings in margarine, but certain colouring matters are prohibited as harmful.

There are at present no regulations about indicator reagents.

All table margarines shall contain 450–550 international units vitamin A and 90 international units D per ounce (16–19 i.u. A and 3 i.u. D per gram). This is by agreement between the Ministry of Food and the manufacturers; there are at present no statutory compulsion to vitaminize margarine. Recently, February, 1954, the Minister of Food has approved a recommendation by the Food Standards Committee that vitaminization of all domestic margarine with A and D should be continued and that the following statutory standard should be prescribed, namely 760–940 i.u. A and 80–100 i.u. D per ounce (27–33 i.u. A and 2·8–3·5 i.u. D per gram). The statement of the vitamin content shall be printed on the wrappers of domestic margarine for retail sale.

Margarine for manufacturing use, such as in bakeries, need not be vitaminized.

Special regulations are in force regarding branding and marking packages and packets.

Holland

Licences are required for manufacture and sale. From time to time regulations are in force concerning the use of certain raw materials; for example, in March, 1953, 5 per cent of the fat content should be rapeseed oil of domestic production and 1 per cent premier jus or other fat from indigenous crude animal fat.

The addition of butter is prohibited since 1942. Margarine shall contain not less than 80 per cent fat, nor more than 16 per cent water.

Preservative in the form of benzoic acid or sodium benzoate is permitted up to a maximum of 0·2 per cent.

Colourings and flavourings, if harmless, are permitted.

There are no regulations regarding indicator reagents.

Vitamins should be present to the extent of not less than 20 i.u. vitamin A per g.

Hungary (1938)

An excise tax was imposed on margarine, fats and oils.

Margarine should contain not less than 82 per cent fat, and not more than 5 per cent butterfat should be contained in the finished product.

Preservatives were not allowed.

Non-injurious colouring matter was allowed.

As indicator reagent 1 g of dimethylamidoazobenzol should be used per 1000 kgs margarine.

Italy

After several changes in decrees since 1934 a new law came into force in November, 1951. This permits manufacture of margarine under annually renewable licence. All mixtures or emulsions made from fats of animal or vegetable origin and containing more than 2 per cent moisture must be known as "Margarine." This shall not have an acidity exceeding 1 per cent expressed as oleic acid and shall not contain any hydrocarbons of mineral origin.

The inclusion of fat obtained from milk is forbidden, and margarine shall contain not less than 84 per cent of its weight as fat.

Only preservatives recognized by the Public Health Board are permitted. (This was earlier specified as common salt and borate of soda, the latter not to exceed 0·2 per cent).

Margarine for domestic use may be coloured with colours not forbidden by law, and the use of flavourings is permitted.

Margarine for inland consumption must have sesame oil added as an indicator. The earlier law specified 5 per cent and a definite colour reaction.

There is no law regarding addition of vitamins.

Norway

A licence is required for the manufacture of margarine. There is at present official control as to the raw materials which shall be used, and the addition of butter may be stipulated.

Margarine shall contain not less than 80 per cent fat and not more than 16 per cent water.

Preservatives, apart from common salt, are prohibited.

Colouring of margarine is allowed, but injurious colourings, as defined by the Authorities, are prohibited. There are no regulations about flavourings.

Indicator reagents are not required.

Margarine must contain vitamins to the extent of 20,000 i.u. A and 2500 i.u. D per kg.

Retail packets must be cubical.

Poland (1938)

Excise taxes were imposed on margarine and fats and oils, except those made from home-grown materials.

Margarine should contain not less than 80 per cent fat with not more than 5° of acidity, and milk fat should not be present in excess of 4 per cent of total fats.

Preservatives permitted were benzoic acid and sodium benzoate in an amount not exceeding 0·2 per cent.

Colouring matters permitted included chrysoidin and phenylazo-beta-naphthol.

As indicator reagent potato starch to the extent of 0·2 per cent in the finished margarine should be used.

Portugal

The regulations specify the raw materials that may be used, namely lard, premier jus, oleomargarine, stearine oil, fish oil, and vegetable oils obtained from palmkernels, coconuts, groundnuts, sesameseed, sunflowerseed and cottonseed.

The admixture of butter is prohibited. 10 per cent milk must be added to the fat-blend. (The obligation to use milk was temporarily cancelled in 1947 and was still so in 1953.)

The minimum fat content shall be 84 per cent and the maximum water content 13 per cent.

Preservatives are prohibited, except common salt and saltpetre, the latter not exceeding 1 per cent as nitrate of potash.

The addition of "a very small quantity" of natural organic colouring is permitted; the regulations specify these organic colourings in an appendix. There are no regulations about flavourings.

It is obligatory to use 0·5 per cent potato flour as indicator.

There are no provisions for additions of vitamins.

Sweden

At present certain official regulations operate concerning raw materials, that should be used, mostly applying to liquid oil. The November, 1953, official standard composition was 45 per cent coconut oil, 20 per cent liquid rapeseed oil, 15 per cent hydrogenated rapeseed oil and 20 per cent hydrogenated whale oil.

If milk fat is present as addition it must be declared.

Margarine shall contain not less than 82 per cent fat, nor more than 16 per cent water.

As preservatives, apart from common salt, up to 0·3 per cent benzoic acid or sodium benzoate are permitted. Antioxidants such as lecithin and citric acid are permitted.

Colouring is allowed, but aniline colours are prohibited.

Diacetyl is allowed as a flavouring.

0·2 per cent potato starch is required as indicator reagent.

Addition of vitamins is permitted, and the Food Commission has specified 30 i.u. A and 1·5 i.u. D per g.

Switzerland

Margarine shall contain not less than 84 per cent fat; if salted, it must not contain more than 2 per cent salt. Butter may be added; if so, at least 10 per cent should be added.

Vegetable lecithin may be added, but no chemical such as preservatives, soda or preparations of diacetyl.

Colouring is permitted by certain dyes and natural colourings.

There are restrictions regarding additions of vitamins.

Retail packets shall be of cubic shape.

Argentine

Margarine includes all edible fats resembling butter. It shall not contain wax or hydrocarbons or any substance injurious to health. It shall be free from rancidity and must not contain more than 1 per cent free acidity expressed as oleic acid. It shall have the appearance of fresh butter and remain solid at 20°C.

Margarine must not contain more than 5 per cent fatty matter derived from milk. It shall contain at least 80 per cent total fatty matter and not more than 16 per cent water.

Preservatives other than common salt are prohibited.

It is prohibited to add colouring matter. The use of flavourings is not covered by regulations.

Margarine shall contain 10 per cent sesame oil or other approved indicator reagent. The use alternatively of 0·1–0·3 per cent of wheat or potato starch has been approved.

Vitamins are not mentioned in the regulations; if their addition is contemplated, approval by the Health Authorities must be obtained.

Packets should be of $\frac{1}{4}$, $\frac{1}{2}$ and 1 kg and must be of cubic shape.

Australia

Each State has its own legislation on margarine, but differences are in matters of detail; substantially the regulations are similar. Licences are required for the manufacture of margarine, and distinction is made between two type

Cooking margarine and Table margarine; for the latter the licence, which is valid for a year, but may be renewed, specifies the tonnage that may be manufactured. Manufacturing premises must be licenced, and in some States the two types of margarine may not be made on the same premises.

Margarine is defined as any substance which resembles butter and is capable of being used as a substitute for butter, the fatty contents of which are not derived exclusively from milk (dripping and lard are excluded).

Cooking margarine is margarine containing beef fat and/or mutton fat in a quantity not less than 90 per cent by weight of the total fat and oil therein. For some purposes between 75 and 90 per cent beef and/or mutton fat may be permitted, subject to certain packing and distribution rules.

Table margarine is margarine which is not Cooking margarine or, in some States, margarine prepared from imported fats and oils.

Margarine shall not contain any foreign substance except the non-fatty solids of milk, salt and prescribed ingredients.

In some States the wording of the regulations are slightly different as regards definitions and ingredients permitted.

The incorporation of butter or butterfat is prohibited, but a very small amount of the latter, derived from skim milk used in the churning process, is allowed; this does not, however, exceed 0·1 per cent.

Indicator reagents.—New South Wales, South Australia, Queensland, West Australia and Tasmania specify the use of not less than 0·1 per cent potato starch or arrowroot. Victoria has no regulation regarding indicators. Queensland and West Australia permit alternatively the use of not less than 5 per cent sesame oil.

Preservatives.—All States except Tasmania prohibit the use of preservatives, which however do not include salt, saltpetre and sugars. Tasmania permits the use of 0·3 per cent boric acid or boron compound calculated as boric acid.

Colourings and Flavourings: New South Wales, Queensland, South Australia and West Australia prohibit the addition of colouring or flavouring matter, but naturally coloured oils and fats may be used. Victoria permits the use in margarine of colourings prescribed under the Health Acts, namely harmless vegetable and animal dyes, such as annatto or carotene, and certain synthetic oil-soluble dyes, such as Naphthol Yellow, Naphthol Yellow S, Yellow A.B. and Yellow O.B. The addition of colouring need not be declared. Addition of flavouring is prohibited. In Tasmania colouring of margarine is prohibited.

Vitamins.—There are no special regulations about vitaminization.

Moisture.—Margarine shall not contain more than 16 per cent.

With exception of New South Wales, all the States require retail packets of less than 2 lbs. to be in cube form.

All States have very detailed regulations about labelling, advertizing and channels of distribution, and they also fix quotas for the amount of Table margarine, that may be made.

Brazil

Margarine may contain refined oils and fats of animal or vegetable origin: one or more of them may be hydrogenated, provided this is declared on the label

The use of one or more of the following cow's milk products, after being submitted to lactic fermentation, is obligatory: (1) Pasteurized milk, full cream milk or skim milk, (2) full cream condensed or evaporated milk, (3) pasteurized milk cream, (4) full cream or skim milk powder, duly reconstituted.

The use of emulsifiers such as mono or diglycerides and lecithin is permissible to the extent of 0·5 per cent of the finished product.

A maximum addition of 10 per cent butter to margarine is allowed, additional to the use of milk for lactic fermentation.

It is forbidden to manufacture margarine containing more than 16 per cent water and less than 82 per cent fat.

As indicator reagent 5 per cent of cottonseed oil or sesame oil, having the characteristc reaction shall be used.

Sodium benzoate not exceeding 0·1 per cent may be used as preservative. Salt (sodium chloride) is limited to 3 per cent. Approved antioxidants are permitted, but must be declared.

Vegetable colouring matters will be permitted on application, other colouring matters are prohibited. Margarine shall be coloured to a certain tintometric strength, 28·3 yellow and 4·3 red on the Lovibond tintometer scale, when still solid.

Diacetyl may be allowed as a flavouring at the discretion of the Authorities, but must be declared.

The addition of vitamin A is obligatory, between 15,000 and 50,000 i.u. per kg. Vitamin D is optional, between 500 and 2000 i.u. per kg.

In addition to complying with above regulations the margarine must be free from rancidity and have an acidity corresponding to not more than 1 ml normal alkaline solution per 100 in the factory and 3 ml. when reaching the consumer; the maximum for melting point is 40°C; it must indicate the presence of "lactic fermentation organisms"; catalyst from hydrogenation must not exceed 4 p.p.m. of the hydrogenated material; the margarine must be free from mould impurities or foreign bodies and contain no substance other than those mentioned in the regulations.

Canada

The individual Provinces have legislated independently on margarine. The governments of Quebec and Prince Edward Island maintain at present a ban on margarine; the others have sanctioned its manufacture and sale subject to licences.

Generally, margarine is defined as any food other than butter, which resembles butter and is made for same purposes as butter, but is made wholly or partly from any fat or oil other than from milk.

The fatty compounds of margarine may be any animal or vegetable oils and fats and their hydrogenated products, but may not contain more than 1 per cent of substances other than fatty acids and fats.

In all Provinces margarine must contain at least 80 per cent fat and not more than 16 per cent water.

Ontario and Newfoundland specify a maximum of 1·4 per cent milk solids, Nova Scotia and New Brunswick a maximum of 0·02 per cent butterfat, which may be derived from the skim milk used. Manitoba, Saskatchewan, Alberta and British Columbia have no restrictions with respect to addition of milk fat, but in most Provinces there are prohibitions about mixing margarine and butter for sale or use in public eating places.

Indicator reagents are not required.

As preservatives benzoic acid and its salts are permitted up to 0·1 per cent, and also common salt. Certain antioxidants are permitted, including lecithin (up to 0·2 per cent by weight), citric, tartaric or ascorbic acid (up to 0·2 per cent by weight) and propyl gallate (up to 0·01 per cent). Used in combination they may not exceed 0·2 per cent. In New Brunswick the only permitted preservative is common salt.

There are no regulations about flavourings.

While Dominion regulations permit the use of colourings for butter, including coal tar dyes up to 1 part in 3500 parts food, the provincial regulations vary. Newfoundland and British Columbia have no special regulations. Alberta prohibits colouring to resemble butter of margarine sold or served in public eating places. In the other Provinces the limit of colour is fixed by law, and the maximum tint is 1·6 degrees yellow or yellow and red combined as measured in the Lovibond tintometer.

Vitamins.—Newfoundland demands a vitamin potency of 16,000 i.u. A and 3200 i.u. D per pound. Other parts in the Dominion are controlled by the Foods and Drugs Act and only specify the maximum amount that may be added to a food as 5000 i.u. vitamin A and 800 i.u. vitamin D in a reasonable daily intake.

There are no regulations about shape of packets, but many regulations regarding labelling and advertizing; these demand as regards vitaminization a minimum in a reasonable daily intake of 2000 i.u. vitamin A and 400 i.u. vitamin D.

Union of South Africa

Margarine is defined as any substance in imitation or form of butter, which has a consistency similar to butter, and which has been manufactured mainly from one or more deodorized vegetable or animal oils or fats.

Margarine may contain pure sugar, salt, milk solids, flavourings, preservatives, and not more than 1 per cent of its composition by weight of one or more emulsifiers.

Margarine shall be clean, sound and of pleasant flavour, reasonably soft to the palate, of firm consistency and capable of being easily spread at normal temperatures.

Margarine may contain up to 10 per cent milk fat; its total fat content shall be not less than 80 per cent, and the water content not more than 16 per cent.

It shall contain not less than 0·25 per cent of starch.

Margarine may contain not more than 0·5 per cent of boron preservative expressed as boric acid.

It may contain harmless flavouring substances.

The maximum colour permitted is one degree of yellow or yellow and red collectively, measured in the terms of the Lovibond tintometer scale, but the addition of colouring is prohibited.

Margarine shall contain not less than 20 i.u. vitamin A and 1 i.u. vitamin D per g.

United States of America

Margarine was until 1952 officially described as Oleomargarine, but either description can now be used officially. The manufacture and sale are subject to many different Federal laws and regulations issued under them. Distinction is often made between coloured and uncoloured margarine, and taxes on these vary between States; in some States the sale of coloured margarine is prohibited.

The Federal Food and Drug Administration lays down certain standards for margarine, in addition to which there may also be certain local regulations in individual States and Territories.

Margarine is defined as all substances, mixtures and compounds, which have a consistency similar to that of butter, and which contain any edible fats or oils other than milk fat, if made in imitation or semblance of butter.

The optional fats for margarine are animal fats and oils (from cattle, sheep, swine and goats), vegetable oils and fats, or a combination of both, except that in combination neither the animal fats nor the vegetable shall be less than 10 per cent of the total weight of the fat. Any or all of the fats may be hydrogenated.

The fats must be emulsified with cream, milk, skim milk, or any combination of non-fat dry milk solids and water in which the solids weigh not less than 10 per cent of the water. These ingredients shall be pasteurized and subjected to the action of harmless bacterial starters. Milk means cow's milk.

In margarine in which the fat is derived solely from vegetable oils the milk ingredient may be replaced by any combination of finely ground soyabeans and water, in which the soyabeans weigh not less than 10 per cent of the water.

Other ingredients, which may be used in margarine, are artificial colouring, certain preservatives, vitamins A and D, limited quantities of lecithin or mono or diglycerides, butter and salt. To retard deterioration in flavour certain antioxidants may be incorporated, such as citric acid, isopropyl citrate and stearyl citrate.

As stated above, milk products must be used for manufacture, except in purely vegetable margarine. The addition of butter is optional, and no limit is placed on the proportion, that may be added.

There are no provisions in Federal laws as to indicator reagents.

Benzoic acid or sodium benzoate or a combination of them may be used as a preservative in a quantity not exceeding 0·1 per cent. As antioxidants following chemicals may be incorporated in the fat-charge: citric acid, or isopropyl citrates (not to exceed 0·02 per cent by weight of the finished margarine) or stearyl citrate (not to exceed 0·15 per cent of finished margarine).

Artificial colouring is permitted, provided one of the permitted colourings (F.D.&C. dyes) are used. Coloured margarine is margarine having a tint containing more than 1·6 degrees of yellow, or of yellow and red collectively, but with an excess of yellow over red, measured in terms of the Lovibond Tintometer scale, or its equivalent.

As artificial flavouring diacetyl, added as such or as a starter distillate, or produced during the preparation of the product, is permitted.

Vitamins.—Vitamin A, with or without any accompanying vitamin D, is optional, except in 6 States where it is compulsory, but if vitaminization is claimed, the margarine must contain not less than 15,000 U.S.P. units vitamin A per pound. Vitamin A may be obtained from fish and whale liver oil, certain synthetic vitamin A concentrates and pro-vitamin A (carotene). The States with compulsory vitaminization are South Carolina, Tennessee, Alabama, Mississippi, Louisiana and Texas.

Finished margarine shall contain not less than 80 per cent fat.

No distinctive shape is specified for packets, but coloured margarine must be retailed as prepacked product, and the nett weight of the contents shall be one pound or less. If artificially coloured or flavoured or containing chemical preservatives it must be declared on the label; pro-vitamin A (carolene) is considered artificial colouring. Vitaminized margarines, like all vitaminized foods, must bear such information as to inform purchasers fully as to their value. The label must also show the common name of optional ingredients, and precise wording is laid down for indication of presence of artificial colouring, benzoate, vitamins, diacetyl, citric acid, isopropyl citrate and stearyl citrate.

Some further regulations apply to coloured margarine as to the type to be used for the printed description of the product, placing of the description, etc.

In addition to the Federal regulations mentioned there are the State laws, which are principally concerned with coloration, labelling, taxation and serving of margarine in restaurants. While earlier few States permitted the sale of coloured margarine, this is now allowed in all but seven States. Certain States place taxes on margarine; two levy higher taxes on coloured than on white margarine.

India

As described on page 261 the Indian type of margarine, Vanaspati, is different from the Western type and consists practically of 100 per cent fatty matter. The present regulations are as follows: Vanaspati should be 100 per cent vegetable fat, consisting of a hydrogenated fat or mixtures of such fats, the limits for melting point being 31–37°C. Sesame oil or hydrogenated sesame oil shall be included in the mixture in quantities sufficient to give the Baudouin reaction, when 20 parts Vanaspati is mixed with 80 parts refined groundnut oil, the Baudouin red colour to be not less than 2 units in a 1 cm cell of the Lovibond scale. Usually 5 per cent sesame oil in the mixture will suffice.

The butyro-refractometer reading at 40°C shall be not less than 48.

The unsaponifiable matter shall not exceed 1·5 per cent.

The free fatty acids shall not exceed 0·25 per cent as oleic.

The moisture shall not exceed 0·25 per cent.

Harmless colourings and flavouring may be used. Diacetyl if used may not exceed 6 p.p.m. Other permissible flavourings are ethyl butyrate, ethyl caproate, ethyl caprilate, iso-propyl butyrate, vanilla, benzaldehyde, amyl acetate, but not coumarin.

The product shall be clear when melted and shall have added to it not less than 300 i.u. synthetic vitamin A per ounce.

Pakistan

The Pakistan regulations for Vanaspati are largely similar to those for India.

Vanaspati shall be made of 100 per cent vegetable fat or oil of which not less than 50 per cent shall be hydrogenated. No fish or animal oil is allowed.

The melting point shall be between 31 and 37°C (± 2°C).

The butyro-refractometer reading at 40°C shall be not less than 48.

The unsaponifiable matter shall not exceed 1·5 per cent, and the free fatty acids, calculated as oleic, shall not exceed 0·25 per cent.

As indicator reagent 5 per cent hydrogenated sesame oil shall be included.

Harmless colourings and flavourings may be used, but if diacetyl is used, it shall not exceed 6 p.p.m.

The moisture content shall not exceed 0·25 per cent.

There are no stipulations regarding inclusion of vitamins.

Vanaspati shall be packed in tins of 36 lbs. content each.

VII. DIAGRAMS OF FACTORY ARRANGEMENTS

Plans based on Votator Coolers

Fig. 102 shows a diagram for a suggested lay-out of a small factory in which the production is based on the use of a Girdler Junior Votator with a capacity of 1500 lbs per hour.

The refined fat-blend is stored in room D in four oil storage tanks (13) and kept liquid by steam or hot water. 2-HP-100 gall.-per minute pumps (14) take the fat-blend to the weighing tank (15) placed above the emulsion pre-mixing tanks (16) in production room C. Three jacketed milk pasteurizers and milk preparation vessels with stirrers and recording thermometers (4) in room B serve to pasteurize, cool and prepare the aqueous phase; the jackets can be heated by a mixture of water and exhaust steam and cooled by refrigerated water. A 1-HP-100 gall. per hour pump (8) delivers the prepared milk to a milk weighing tank (12) next to the oil scales above the pre-mixers. In the milk room are also placed sterilizers for mother cultures (5) and starters (6) for the margarine milk, as well as a test cabinet (7) for these stages. There is also the tank (9) for cooling water, a cooling cabinet (10) and water pump (11). The receiving room A for milk supplies houses a tank (1) for emptying milk cans, a can washer (3) and a pump (2) for delivering milk to the preparation room.

In the main processing room C the two emulsion pre-mixing tanks (16) are placed on a platform with the oil and milk weighing tanks above. The emulsion tanks alternately supply the emulsion to the 3-HP emulsion pump (17), which feeds the Votator A-unit (18) under a pressure of 300 p.s.i. The semi-fluid material from the A-unit sets sufficiently in the B-unit (19) to be passed a short distance to a moulding and wrapping unit (20), and the wrapped blocks are finally cartoned before being delivered to a packing table (21) for filling into boxes. These are then conveyed to the cold storage room E for warehousing.

The plan also shows accommodation for compressors (22) and condenser (23) in room G, boiler plant (24), storage area F for boxes, wrapping materials and other dry goods, factory office location H, dressing rooms, etc., K and L and general office J.

The whole building takes up a ground area of 84 ft. × 64 ft. All machinery is driven by electric power obtained from outside.

For factories with larger output the lay-out may be on the same general lines, scaled-up to accommodate the more elaborate plant and increased space required. As an example may be mentioned a factory for a weekly out-

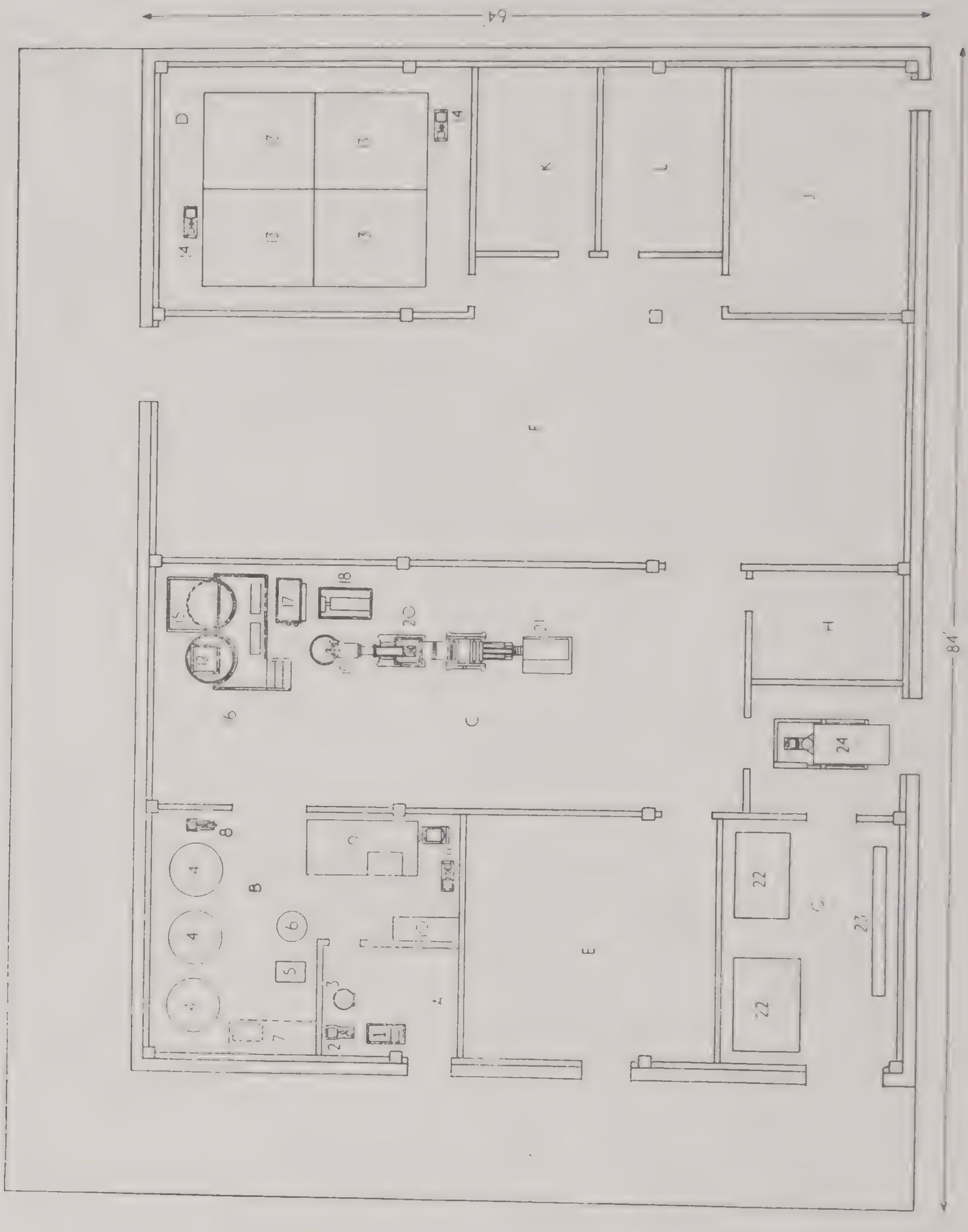

Fig. 102. Arrangement based on Votators (Courtesy: *Girdler Corp., Louisville, U.S.A.*).

put of 500 tons, produced by continuous working during 120 producing-hours. It is assumed that the fats and oils are received in the form of refined deodorized individual materials and not pre-blended before deodorization.

The fatty raw materials amount to 415 tons per week and consist of hydrogenated fats, semi-hydrogenated fats, solid fats such as coconut and palm oil, and liquid oils: they are received from a refinery in the neighbourhood, and it should therefore be sufficient to have storage accommodation for about 3 days or 250 tons, for which 5 storage tanks of 30 tons each, 4 of 20 tons and 2 of 10 tons are required.

The aqueous phase is made from half milk and half water, the milk being ripened before mixing. The amount required will be 1,450 gall. per day. To deal with this a receiving tank, pump, plate pasteurizer and 2 storage tanks of about 800 gall. each are required; if the milk used is dissolved skim milk powder, a dissolving tank is needed. Four-400 gall. ripening vessels should be provided. The dairy which is preferably located in an upper story should further accommodate 2-100 gall. factory starter tanks and water bath equipment for 4-2 gall. starter cans, all based on ripening periods of 12–18 hours.

A room should be provided, also in an upper story, for preparing ingredients, such as salt and preservative solutions for mixing with the prepared milk, for example, 2-250 gall. stainless steel tanks. Two-200 gall. tanks for lecithin solutions and 2-100 gall. tanks for emulsion stabilizers should also be provided, as well as smaller tanks for colour and vitamin solutions.

The production is based on the use of 2 Girdler Votators of 4500 lbs per hour output each, but most manufacturers would provide a third Votator as a stand-by for safety. Each Votator should have 2 mixing vessels for pre-emulsification, each of a capacity for half-an-hour's supply of emulsion, i.e. 2-1·25 ton mixers. Furthermore, for each Votator there must be arranged a 1 ton blend composition tank with weighing attachment and a 100 gall. milk-water mixing and measuring tank.

The pre-emulsion tanks supply the pumps for the Votators, each of which requires refrigeration for their 3-cylinder A-units to the extent of about 65,000 Calories per hour. With correct processing conditions and adjustment of temperatures in A- and B-units the solidified product can be passed on a short length of conveyor direct to the moulding, wrapping and cartoning machine, which at a rate of output of 75 packets per minute can cope with the production from one Votator, if the margarine is packed in 1 lb blocks; if packed in ½ lb blocks, 2 wrapping machines must be available for each Votator. Placing the packets in cardboard or wooden boxes should preferably be done mechanically, as the packets, if not cartoned, are rather soft for manual handling.

Warehouse space is usually provided for 10 days' production, or about 700 tons margarine. The warehouse should be dimensioned to give 9–10 sq. ft. floor space per ton margarine, depending on height of stacks and on the passage-ways required.

In addition to refrigeration for Votator cooling some should also be provided for cold water for milk cooling and for maintaining suitable storage temperature for margarine in cold store.

Plans based on Cooling Drums and Complectors

Figs. 103 (*a*), (*b*) and (*c*) are sketches of a section and two floor plans of a factory, in which the processing is based on the use of the Gerstenberg and

Agger Diacooler and Complector, of which there are two units, each designed for an output of 2 tons per hour, or 150-170 tons per week on day shift.

The fatty raw materials are received in room A and melted out there on grid-tank melters, or if received liquid are pumped via weighing machine (1) to liquid fat storage room B, where there is tank accommodation for storage of 95 tons. Storage is also provided for about 50 tons in tanks in rooms A and C. The fatty materials are pumped by measuring pumps to the blend mixing and tempering tanks (2) of 1 ton each, of which there are four for supplying the emulsifier units.

Milk is received in room D into weighing tank (3) and pumped to milk storage tank (4) in room E, where plate pasteurizer (5) is also situated. A tank (6) for dissolving milk powder is also installed in room D. The pasteurized cooled milk is run to the milk ripeners (7) in the milk processing room F, where there is also a water bath (8) for preparing starters and cultures. The three ripeners are of 300 gall. capacity each. The ripened milk is pumped as required to two measuring vessels (9) of 60 gall. each.

In room G various ingredients are prepared, such as colour, emulsion stabilizers, salt solution, etc., for addition in the emulsion-mixing tanks (10).

There are four of these 1-ton emulsion mixers, two for each set of cooling drum, and they are charged by gravity from milk and blend measuring tanks (9) and (2). The emulsators (11) pump the emulsion to the drums (12), from which the solidified emulsion flakes fall direct into the silo hopper (13) for the Complectors (14), which discharge the finished margarine into trucks. The drums are placed sufficiently high on the emulsification platform to permit a band conveyor (15) to be inserted under the scraper knife, so that the flakes can be conveyed to a funnel (16) and be discharged direct into trucks placed underneath. This arrangement is preferred by some manufacturers for special bakery qualities of margarine, which is then kneaded and plasticized by several workings on the turn-table (17).

Two blenders (18) are provided in case the manufacturer wishes to pack qualities requiring blending.

The margarine from the Complector is taken by trucks to the packing and wrapping machines (19). Bulk packing takes place in room H between turn-table and wrapping machines. A room L is provided on the ground floor as a resting and maturing room for margarine in trucks after Complector treatment and before packing. A band conveyor (20) transports boxes with packed margarine to warehouse J.

Hot and cold water tanks (21) and (22) are on the top floor. Room K on the first floor houses compressors (23) and condenser (24) for refrigeration, switchboard (25) for power distribution and some auxiliary machines (26). The boiler plant is in a separate building.

Above the maturing room there is on the first floor a store M for packing material and sundry goods. A space N on the same floor is used for preparing packing material for sliding down to the packing locations. A light-well O admits light from above to the packing section. Above the warehouse are rooms P, Q and R, used as canteen and cloakrooms.

Room S on the second floor is available for storage of fats in barrels or drums and for other purposes. T are hoists for the different sections. U is the entrance and checking-in place for employees, W washrooms, and X a dispatch platform at the end of the building, which covers an area of about 180 ft. × 64 ft.

Plans based on Churns-Drums-Multiplex Roller

Figs. 104 (*a*) and (*b*) shows sketches of a plan for a factory with a production of 250–300 tons per week on single shift, based on the churn-drum-multiplex-blender system. The factory occupies a ground area of 160 ft. by 60 ft. and has a 4-storied section and cellar at one end, 60 ft. by 30 ft., the rest being 2-storied, except the packing section which has only one floor.

Storage for 200 tons liquid fatty material is provided in rooms A and B on the ground-floor, where there are 6 rectangular and 6 round tanks of various sizes, and for 100 tons solid fats in the cellar C. Melting out of the solid fats and tempering of the blend takes place on the top floor in room D, where there are 6 melters (1) and also some oil tempering tanks (2). There is also in this room some extra storage space for barrels and drums. Weighing, mixing and tempering of the blend is completed in the room E below in tanks (3). In this room are also some smaller tanks for preparing fat-soluble ingredients such as lecithin and colour solutions.

Milk is received in the ground-floor room F, where there is installed a receiving weighing tank (4) and a pump (5) for lifting the milk up to room G, where there are 2 × 800 gall. milk storage tanks (6). The amount of milk is about 10 per cent of the fat-blend, the remainder of the aqueous phase is water and salt solution. In room G the milk is pasteurized and cooled before storage or before being ripened. For the latter process 4 × 400 gall. ripening tanks (7) are provided. In this room there are also smaller ripeners for starters and thermostats for cultures, as well as a tank for dissolving milk powder, when this is used. Tanks for preparing water soluble ingredients and salt solutions are placed in this room.

From the tempering and weighing tanks and from the dairy the constituents run by gravity to smaller measuring tanks, at the churns (8) on the floor H below. There are 5 churns, each with a working capacity of 1·5 tons. From these, pumps (9) supply the emulsion to the feeding trough of 2 cooling drums (10), each of 3 tons per hour capacity, placed on a platform in churn room H and sufficiently elevated to permit the solidified emulsion to drop into trucks placed under them on the same floor.

The trucks are transported into the adjacent space J on the same floor for a few hour's rest and maturing; they are then emptied through an opening (11) in the floor into the hopper (12) with extruder (13) and kneaded on multiplex roller (14), placed on the ground floor in room K. This multiple has

3 pairs of porphyry rollers with band conveyors between the pairs and has a capacity of 6–8 tons per hour. Through a compression extruder (15) it discharges the consolidated margarine, sliced into suitably sized pieces, on to an elevating band conveyor (16), which lifts the product to a higher level and up to a reversible band conveyor (17) at right angles, that deposits it on one of two paddle kneading tables (18), which are placed sufficiently high to discharge the worked margarine into trucks on the floor.

The margarine can then either be transported to the packing section L or be placed temporarily in a rest room M for kneaded margarine.

In the packing section are 4 × 2 cwts blenders (19), from which margarine can be packed in bulk boxes and transported to cold store N_1 on the first floor by conveyor and elevator (20), or it can be packed in packeting moulding and wrapping machines (21), of which 2 for half-pound packets will turn out 1 ton per hour each, the third for pound packets 2 tons per hour. Boxes with packed margarine are placed on conveyor (22) and stored in warehouse N_2 on the ground-floor.

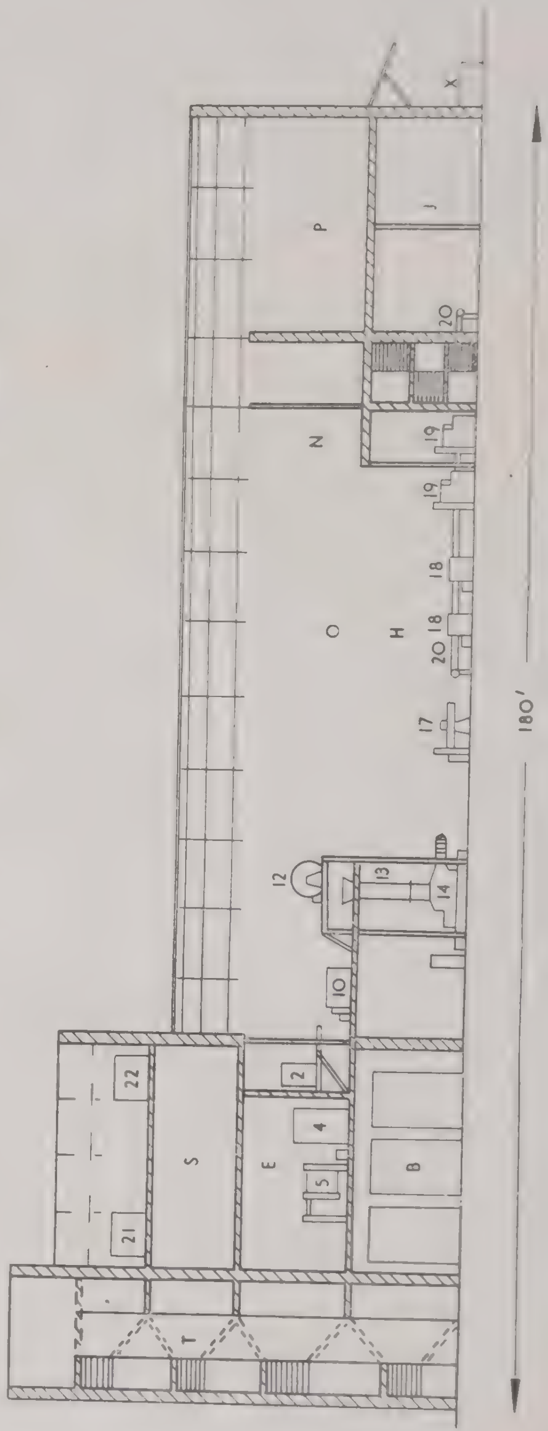

Fig. 103*a*. Arrangement based on Complectors.

Above part of the kneading room K and rest room M is a store T for packing materials and other goods: packing materials are brought by chute to the packing location.

O is a room on the ground floor for truck washing. R is a room on the same floor for housing compressors (23) and condenser (24) for refrigeration.

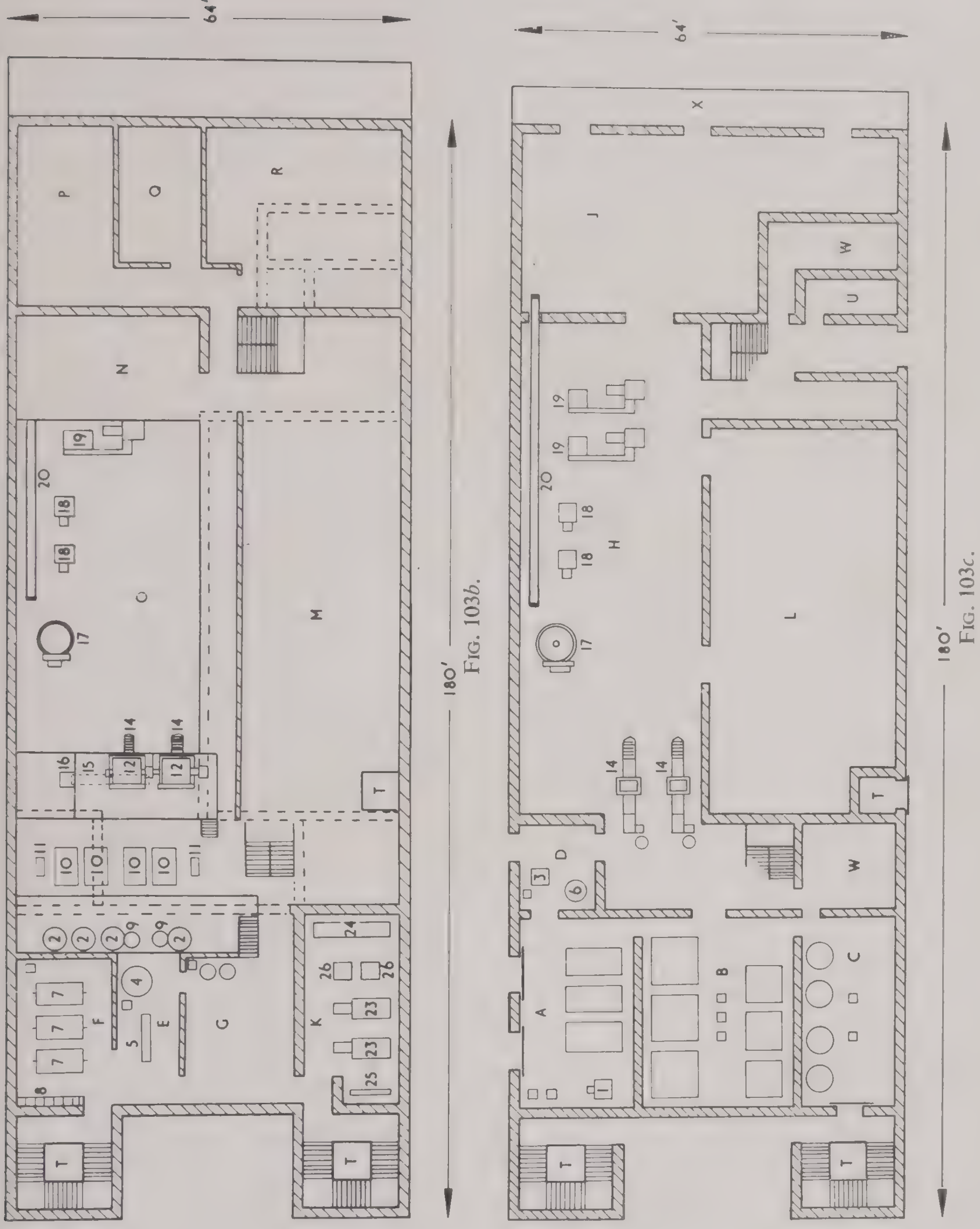
64'
180'
P
Q
R
N
O
M
T
20
19
18
17
16
15
14
12
11
10
2
9
4
5
7
8
E
F
G
K
24
26
23
25
64'
180'
X
J
W
U
H
L
D
3
6
1
A
B
C

FIG. 103*b*.

FIG. 103*c*.

FIG. 103.—Arrangement based on Complectors.

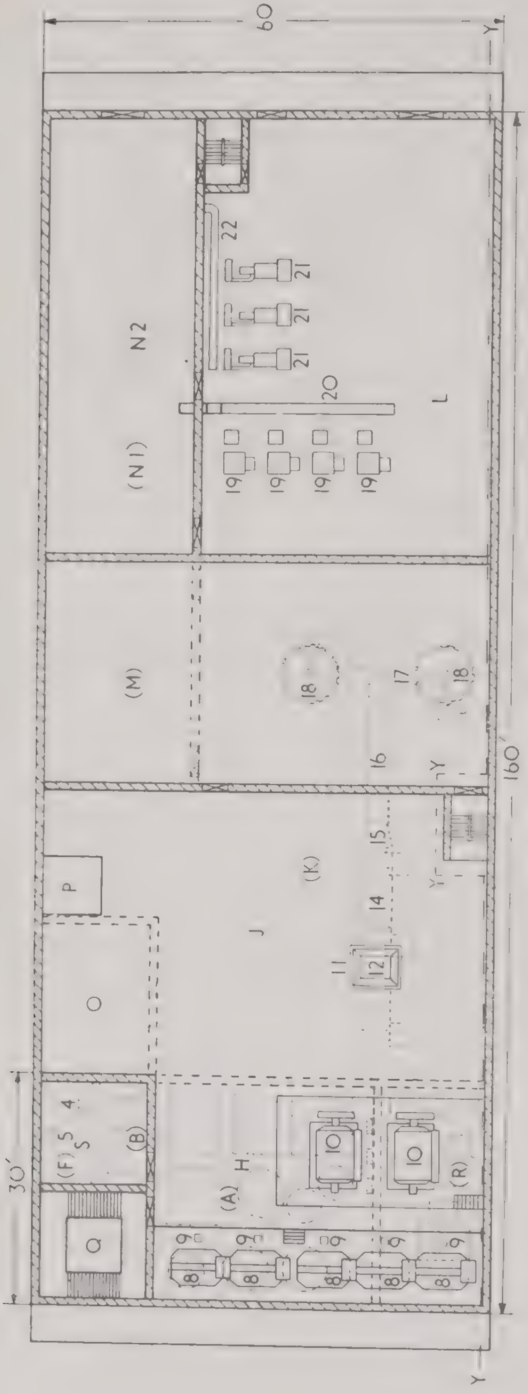
60'
Y
N2
(N1)
22
21
21
21
20
L
19
19
19
19
(M)
18
17
18
16
Y
160'
(K)
15
14
J
11
12
P
O
30'
(F)
5
S
4
(B)
H
(A)
10
10
(R)
Q
9
8

FIG. 104*a*. Plan along X—X.

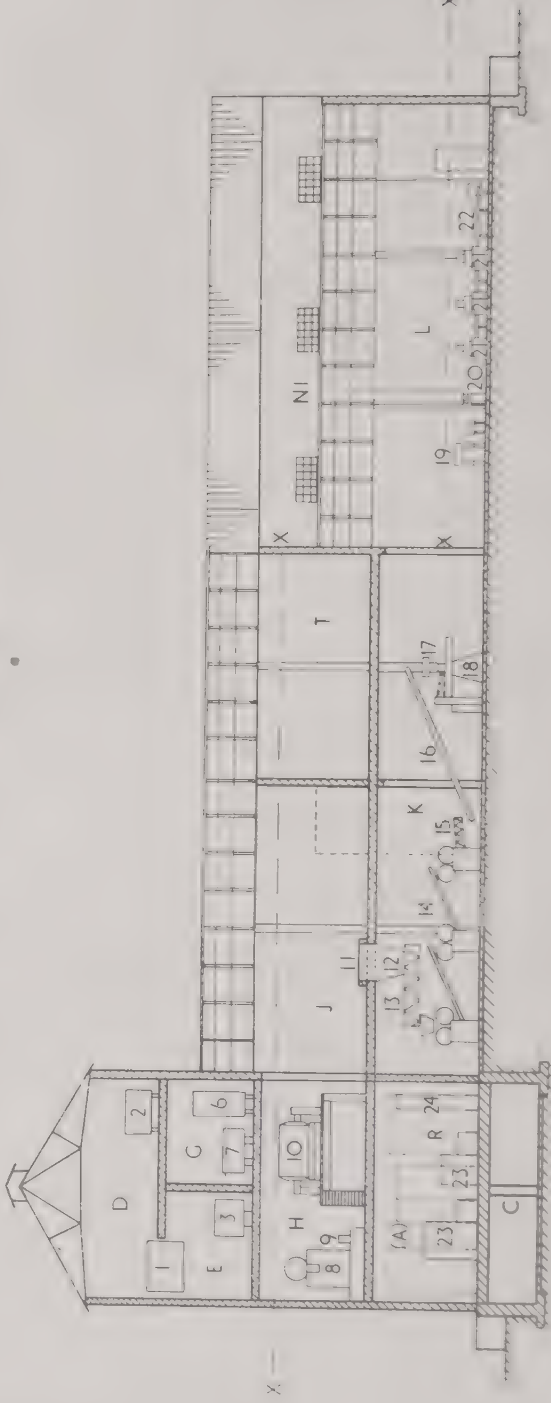
X
N1
L
22
21
20
19
T
17
18
16
K
15
14
11
12
13
J
2
6
G
7
10
D
3
H
9
8
I
E
R
24
23
(A)
C

FIG. 104. Factory plan (see text, p. 313).

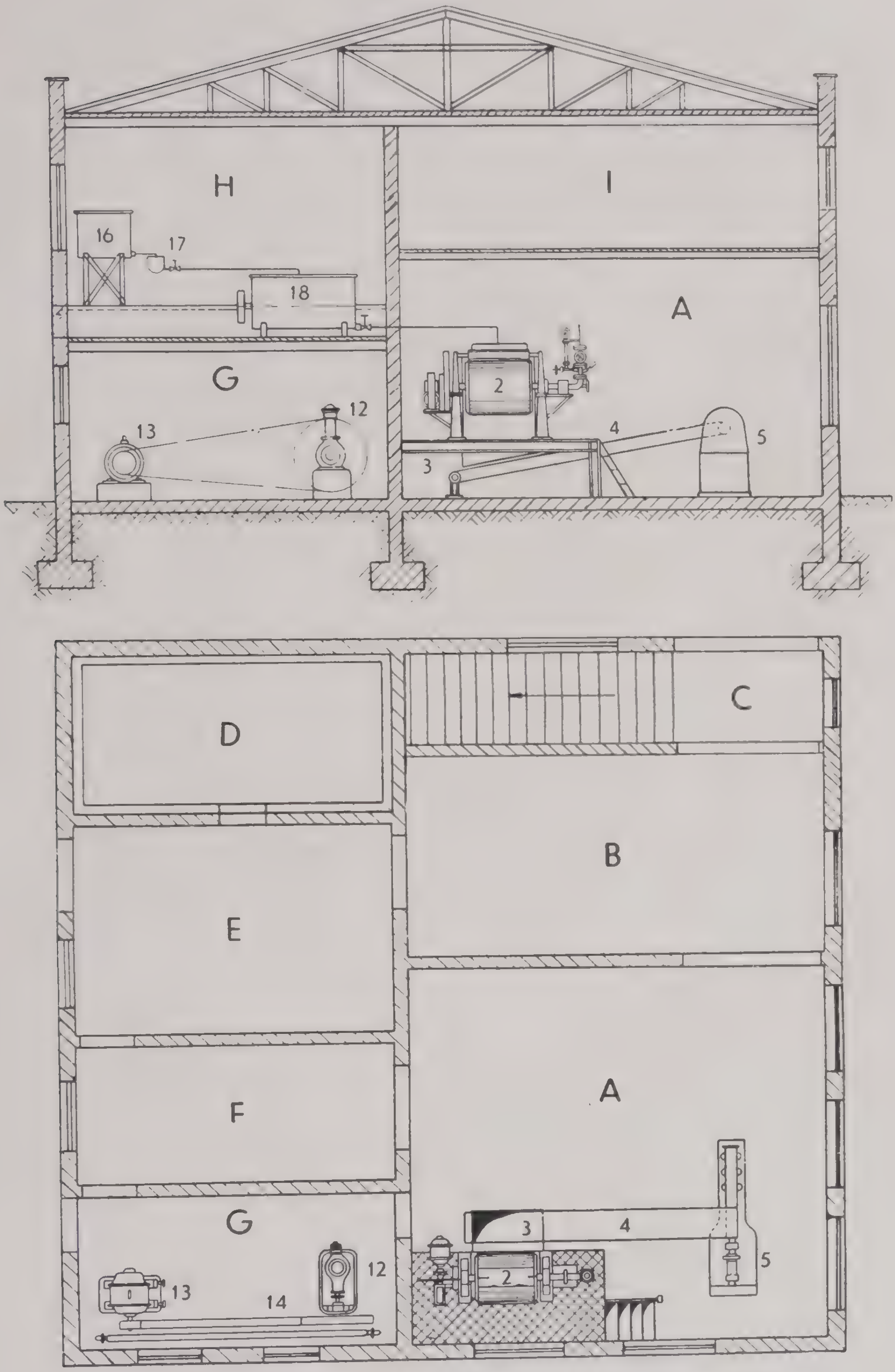
H
I
16
17
18
A
G
2
12
13
4
5
3
D
C
B
E
A
F
G
3
4
2
12
13
14
5

FIG. 105. Manufacturers' plan for layout of machinery in a small factory.

and some auxiliary machinery. P and Q are service lifts. S on the first floor, off the churnstage, provides accommodation for process control tests and analysis of moisture.

Boilers for steam and power supply, as well as repair shops, cloakrooms and canteen, are in separate buildings.

Plan based on the Lardin System

Fig. 105 shows manufacturer's plan for a lay-out of machinery in a small factory, working on the Atlas Lardin system. A is the processing room, B the packing room, C a staircase to a room I on the upper floor for storage of fats, packing materials, etc., D is a cold store, E warehouse and dispatch, F laboratory, G engine room for compressor, condenser and motor, and H on the upper floor melting-room and milk preparation room.

The mixing and melting of the fat-blend is carried out in tank (16); it is weighed out in (17) and mixed and tempered with the prepared milk in emulsifier-mixer (18). From there the liquid emulsion runs to the feeding trough which in the Lardin system is placed at the top of the cooling drum (2). (3) is the hopper for catching the emulsion flakes and depositing them on band conveyor (4), which drops them into the continuous kneading plant, the Mycronisator (5), from which the finished margarine is collected in trucks. (12) is the refrigeration compressor, (13) its motor and (14) the double-pipe condenser.

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